INTERNATIONAL
HELLENIC
UNIVERSITY

ENVIRONMENTAL IMPACT ASSESSMENT OF MEAT PRODUCTS IN GREECE

Kanta Maria-Evrydiki-Spyridoula

SCHOOL OF ECONOMICS, BUSINESS ADMINISTRATION & LEGAL STUDIES
A thesis submitted for the degree of
Master of Science (MSc) in Environmental Management and Sustainability

January 2019
Thessaloniki – Greece

Student Name:	Maria-Evrydiki-Spyridoula Kanta
SID:	1105170005
Supervisor:	Dr. Georgios Banias

I hereby declare that the work submitted is mine and that where I have made use of another's work, I have attributed the source(s) according to the Regulations set in the Student's Handbook.

January 2019
Thessaloniki - Greece

Abstract

Nowadays the agriculture and food sector produce more and more food in comparison with previous decades. The increased world population as well as dietary changes are the main causes of the high demand in food products. Especially, meat industry is one of the largest industries in the world with high demand in energy and resource consumption. Consequently, the contribution of meat industries to environmental issues like resource depletion, air emissions and land degradation is high significance. Nevertheless, meat companies are not entirely aware regarding their environmental footprint. Life Cycle Assessment (LCA) is a scientific method applied to evaluate the environmental impacts arisen during meat products' life cycle.

This thesis focused on the evaluation of environmental impacts resulted in meat production chain. More specifically, an LCA study was conducted in an intensive production system applied in a dairy cattle farm in the region of Thessaloniki, Greece. In the LCA the current situation in the farm under study was compared with an alternative scenario which encompassed the valorisation of animal by-products. Therefore, a comprehensive overview took place regarding the environmental performance of both scenarios.

The most environmentally friendly scenario was those with the utilization of animal by-products. This scenario included the anaerobic digestion of dairy cattle manure for biogas production (electricity, heat) as well as the utilization of digested manure as organic fertilizer to substitute Nitrogen (N) and Phosphorus (P) used for feed and crop production. Therefore, it is crucial meat companies to be aware regarding their environmental performance and after the detection of their weak and key points for impact mitigation to choose the most effective actions which can reduce their environmental impacts leading to a more sustainable society.

Keywords: life cycle assessment (LCA), environmental performance, dairy cattle farm, Greece

Preface

This dissertation was written as part of the MSc in Environmental Management and Sustainability at the International Hellenic University. Through my studies at the International Hellenic University's MSc in Environmental Management and Sustainability, I gained valuable knowledge that expanded my horizons as well as a stronger interest in this field.

In addition, I would like to express my gratitude to my supervisor Dr Georgios Banias, for his valuable advice and continuous guidance as well as the opportunity to work on this interesting project. I would like also to thank Ms Maria Lampridi for her valuable advice and guidance throughout my thesis.

Finally, I am grateful to my family for their love and unfailing encouragement. Thanks also to my friends and especially to my best friend and colleague Anthi, for their continuously support during my postgraduate studies.

Kanta Maria-Evrydiki-Spyridoula

29/01/2019

Contents

1. Introduction

Climate Change (CC) is one of the most crucial environmental issues that humankind is facing during the last decades. In this context, livestock production has received most attention for its environmental impacts (Steinfeld et al., 2006). The growth of world's population, trade liberalization, globalization of food systems, urbanization, nutritional transitions of dietary patterns as well as consumer's preference to consume food which contain rather high content in animal protein are examples which have as a result the increased meat consumption. In addition to that, sensory attributes and cultural habits all over the world influence the consumer preferences regarding meat products (Djekic & Tomasevic, 2016). Economy, society and environment which are the three pillars of sustainability are affected by meat production and consumption (Allievi et al., 2015).

The livestock sector is one with increased need for natural resources such as land, water and energy and responsible for the emission of severe pollutants on air, water and soil (Djekic, 2015). It is worth mentioning that, meat production contributes between 4.6 and 7.1 gigatonnes of Greenhouse Gases (GHGs) each year to the atmosphere, which represents a share of 15% to 24% of GHGs emissions (Skunca et al., 2015). Furthermore, manufacturing processes such as slaughtering and meat processing cause environmental impacts being resulted from emissions into the environment or from the resource consumption (Djekic & Tomasevic, 2016). Especially, meat has the greatest environmental impact compared to other food products, because of the inefficiency of animals in converting feed to meat (Djekic, 2015). Moreover, the refrigeration of meat products is responsible for ozone depletion and global warming (Coulomb, 2008). Last but not least, during the cooking stage the emission of a large amount of GHGs take place because of energy consumption (Djekic & Tomasevic, 2016).

In addition to the above, another environmental aspect is the discharge of waste water and solid waste. Several procedures are responsible for the production of waste water in meat industry. For instance, these are the following: washing of livestock, carcass and offal, cleaning of equipment, work surfaces and floors as well as worker's personal hygiene. The waste water generated by meat sector includes pollutants such as blood, manure, fat and undigested stomach content. Moreover, solid waste comprise of inedible products like bone and skins, as well as several packaging materials. This means that inefficient waste management processes can create pollution risks (McAuliffe et al., 2016). In European Union, the regulation 1069/2009 directs the usage of animal by-products (Djekic et al., 2016).

As can be seen, intensive livestock production has a detrimental impact on the environment. It is worth mentioning that, worldwide beef and bovine dairy production combined is responsible for the emission of 4623 million tonnes CO_2-eq per year, significantly higher than the production of 668 million tonnes CO_2-eq per year arisen by pig production as well as the production of 606 million tonnes CO_2-eq per year emitted by chicken production. Taking into consideration that, meat production and consumption is predicted to be increased more in the direct future, it is crucial sustainable agriculture to be implemented within livestock supply chain (McAuliffe et al., 2016).

1.1. Aims and Objectives

As far as meat companies concerns, it is great importance to be conformed with regulations and policies in order to improve their environmental performance. The environmental practice in food industries is the principal factor that influence their environmental performance. These practices can be passive or reactive procedures which target to be in compliance with prerequisites as well as introduce primary end-of-pipe solutions, to more developed or proactive strategies which improves a company's contribution to sustainable development (Guerrero - Baena et al., 2015; Murillo-Luna et al., 2011). Life Cycle Assessment (LCA) is a scientific methodology for assessing and comparing the environmental impacts of livestock production systems during their life cycle (Tsutsumi et al., 2018). The implementation of LCA tool in a company's product can offer added value and enhance company's competitiveness in the International market (Bartzanas et al., 2015).

The LCA method comprises of four main stages. The first stage is the definition of the scope and goal of the study, including the description of the functional unit, which aim to create a reference to which the inputs and outputs are related as well as the definition of the system boundaries, which are the processes of a complete system included under the assessment (Ogino et al., 2007; Skunca et al., 2018). The second stage is the inventory analysis in which all resources used and all the emissions released in the environment relating to system boundaries, are recorded. Also, the third stage is the impact assessment in which the data of the life cycle inventory are interpreted in terms of environmental impacts such as global warming, acidification and eutrophication. Lastly, the fourth stage is the interpretation of the results (Ogino et al., 2007).

In case of Greece, there are few LCA studies which evaluate the environmental impacts of livestock production. In particular, there had not been published LCA studies associated with meat products until 2015. The first study was conducted by Bartzanas et al. (2015) who applied LCA methodology to the raw – milk produced in a dairy cattle producing farm located in Greece, in order to assess its environmental impacts throughout product’s lifecycle. In addition, Giannenas et al. (2017) carried out LCA method in a group of broilers raised on a commercial Greek farm to assess the environmental performance of three broiler production systems.

The aim of this study is to evaluate the environmental impacts associated with meat production. First of all, a literature review is carried out investigating scientific papers which applied LCA methodology in livestock sector, worldwide. In this way, valuable information can be extracted regarding the livestock production systems as well as the most important environmental impacts aroused from various emissions into the environment such as CH_4 and NH_3, from the consumption of resources associated with production processes and from the discharge of waste water and solid waste. In addition, the LCA methodology will be applied in a specific Greek Meat Company to provide a first evaluation of the environmental impact potentials of beef production in Greece. Afterwards, modifications and improvement practices will be proposed in order to reduce the total ecological footprint and thus to move to a more sustainable livestock production.

2. Literature Review

Most studies published so far implemented only a “cradle to farm-gate” LCA rather than “from cradle to grave” LCA (De Vries & De Boer, 2010). Taking into consideration specific methodology, investigation of research papers took place.

2.1 Livestock production and methodology used

Livestock production is responsible for several damaging effects on the environment. For instance, the uninterrupted usage of land, water and energy, which exacerbate the depletion of natural resources as well as the release of harmful emissions into the air, water and soil during the execution of procedures related to meat production (McAuliffe et al., 2016). The Food and Agriculture Organization declares that livestock sector is responsible for 18% of total GHGs due to emission of carbon dioxide from fossil fuel combustion and deforestation, emission of methane from manure and enteric fermentation by ruminants, and emission of nitrous oxide from utilization of fertilizers for cultivation purposes (De Vries & De Boer, 2010).

A literature review was performed by investigating published scientific papers available through Scopus, Science Direct and Google Scholar in the domains of environmental impacts in the meat chain. In this study there were no geographical restrictions imposed. The selection criteria chosen to identify the relevant research papers, and then to enable a comparison of environmental impacts of meat produced, are the following:

- Studies that examined the environmental impacts of meat using LCA
- LCA of systems that produce beef, pork and chicken meat
- Studies which use attributional LCA
- At least cradle to farm-gate LCA
- Chronological period from 2007 to 2018 to be covered

LCA studies which production systems produce milk or eggs as well as studies that concern processed or cooked meat were excluded from this literature review. For instance, the study implemented by Perez-Martinez et al. (2018) for evaluation of environmental impact of two ready-to-eat canned meat products using LCA. It is worth mentioning that, the majority of LCA studies assess only the production stages until the farm gate, and exclude subsequent stages like processing, retail or household (De Vries & De Boer, 2010). Therefore, this chapter includes studies that evaluate at least all production stages until the farm gate. Additionally, studies which evaluate more stages related to meat chain after the farm gate, are included in order to have a more complete understanding concerning the environmental impacts of meat's life cycle. Moreover, the majority of LCA studies which concern the livestock products use attributional LCA, which aim at quantification of the environmental impact of a product being in a status quo situation (De Vries & De Boer, 2010). As a consequence, this chapter contains only attributional LCA studies during the period from 2007 to 2018.

According to above mentioned criteria, a selection of 15 LCA studies concerning the beef, pork and chicken production is provided in tables in the following sections. Furthermore, taking into account the main steps for the LCA implementation, the research focus of each study, the participated entities from which the data were collected, the system boundaries, the functional unit and the impact coverage are recorded. Afterwards, a comparison of the results is provided for a better understanding of the environmental impacts during the meat production and the hotspots that contribute to the environmental effects. Nevertheless, it is important to mention that, LCA results are difficult to compare. This is because of some studies follow a "cradle to grave approach", while other studies adopt a "cradle to gate approach". Also, some studies take into account the emissions or removals owing to land use while others do not consider them. Furthermore, although some studies use similar objects of analysis, there are differences in relation to functional unit definition, allocation methods as well as the characterization of the processes (Dick et al., 2015).

2.2. Selection of LCA studies

In this chapter the description of chicken, pork and beef production systems as well as the comparison of scientific papers in this field took place for a better understanding of the environmental impacts related to meat production.

2.2.1 Chicken production

Chicken has become one of the most popular for consumption meat product worldwide (Gonzalez-Garcia et al., 2014). The increased world population as well as poultry meat's high content of proteins, vitamin B and minerals have as a result the high demand of this product (Lopez-Andres et al., 2018). It is worth mentioning that, chicken production systems are classified in two categories depending on the farming operations. The conventional chicken which is raised on farms based on industrial feed, and the free-range chicken which is raised outside with vegetable diet (Gonzalez-Garcia et al., 2014). Although broiler meat production has a better environmental performance than other meat productions, it is essential to develop more sustainable systems in this sector (Lopez-Andres et al., 2018).

In this literature review five studies have been selected, which assessed the chicken production through LCA to determine the environmental hotspots. These are a Vertically Integrated System being dependent on concentrated feed (Cesari et al. 2017) and three conventional chicken production systems based on a variety of ingredients such as maize, wheat, corn and soybean meal (Skunca et al. 2018; Kalhor et al. 2016; Katajajuuri et al. 2007). Last but not least, there is a study which research focus is on the comparison of broiler production scenarios. The one included imported chickens from Brazil produced in standard intensive systems, having as feed principally locally maize and soybeans. The other included chickens produced in France in standard intensive system having as feed, maize, wheat and rapeseed as well as soybean from Brazil (Da Silva et al. 2012).

Table 1: List of selected LCA studies of chicken meat production.

Study	Sample	Research Focus	Functional Unit	System Boundaries	Impact Coverage[a]
Chicken					
Skunca et al. (2018)	119 farms, slaughterhouses, meat processors, retailers and 500 households in Serbia	LCA of chicken meat chain	Kg consumed meat	Farm, Slaughtering, Processing, Retail, Household	GWP, AP, EP, OD,CED
Cesari et al. (2017)	80 broiler farms and a slaughterhouse in Italy	LCA of broiler Vertically Integrated System	Kg carcass weight	Farm, Slaughtering, Packaging	GWP, AP, EP, TE, EU
Kalhor et al. 2016	40 broiler farms and a slaughterhouse in Iran	LCA of chicken meat production in summer and winter seasons	t live weight	Farm, Slaughtering	ADP, AP, EP, GWP, ODP, HTP, FAETP, MAETP, TETP, PhOP
Da Silva et al. (2012)	Production scenarios of chicken in Brazil	LCA of 2 production scenarios of chicken	1 ton chicken cooled and packed	Feed Production, Farm, Slaughtering,	CC, AP, EP, TE, LO, CED
Katajajuuri et al (2008)	20 broiler farms in Filand	LCA of broiler production	t live weight	Farm, Slaughtering, Packaging, Delivery, Retail	CC, AP, EP, OF

[a] Impact Coverage: Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), Ozone Depletion (OD), Cumulative Energy Demand (CED), Terrestrial Ecotoxicity (TE), Energy Used (EU), Abiotic Depletion Potential (ADP), Ozone layer Depletion Potential (ODP), Human Toxicity Potential (HTP), Freshwater Aquatic Ecotoxicity Potential (FAETP), Marine Aquatic Ecotoxicity Potential (MAETP), Terrestrial Ecotoxicity Potential (TETP), Photochemical Oxidation Potential (PhOP), Climate Change (CC), Land Occupation (LO), Ozone Formation (OF)

2.2.1.1. Comparison of LCA studies

The above selected studies having assessed the life cycle of meat products showed that processes related to farm, especially feed and crop production and broiler housing had the highest contribution to all impact categories examined. Specifically, Katajajuuri (2008) estimated that the production of fodder and broiler housing contributed significantly to the impact category of Global Warming Potential (GWP) with 36% and 29%, respectively, of total impact, due to the emissions of energy consumption, the nitrous oxide emissions contained in fertilizers as well as nitrous oxide and methane from manure handling. Moreover, broiler housing and production of fodder were responsible for over 80% for Acidification Potential (AP) and Eutrophication Potential (EP) due to ammonia evaporation of manure as well as the cultivation of crop which contribute to the nutrient run-off and leaching (Katajajuuri, 2008). Likewise, Kalhor et al. (2016) showed that the broiler production stage was the main contributor for all impact categories examined while feed production, its transportation and processing affected significantly all impact categories except AP and EP. This difference regarding the feed production and its influence in AP and EP could be attributed to differences in the system studies such as differences in broiler factor and emissions factors (Katajajuuri 2008; Kalhor et al., 2016).

In line with the previous studies, Cesari et al. (2017) estimated that that the broiler fattening, and the production of feed were the most impactful stages, with the soybean meal to affect dramatically the GWP. The results showed that the values of the environmental impacts regarding the broiler production in Italy were greater than those in other countries with an average of GWP of the broiler production to be 5.52 kg CO_2 eq. per kg of carcass weight compared to the International literature GWP values which vary from 2.5 to 4.4 kg CO_2 eq per kg of chicken carcass weight (Cesari et al., 2017). The AP was 28.4 g SO_2 eq per kg carcass weight, EP value was equal to 18.4 g PO_4^{3-} eq and Terrestrial Ecotoxicity (TE) was 9.56 g 1.4 DCB eq. These values are in line with other studies in this field (Cesari et al., 2017). Similar to previous studies, De Silva et al. (2012) indicated that feed production was the main contributor to all impact categories, followed by the chicken production while the slaughtering had the lowest contribution.

The results estimated by Skunca et al. (2018) taking into account the impact categories listed in table 1 are comparable with the other selected studies. Specifically, the average GWP was equal to 3.62 kg CO_2 eq included all examined stages, which is lower than those obtained by Cesari et al. (2017) (5.52 kg CO_2 eq). Furthermore, regarding the farm gate Skunca et al. (2018) found the Cumulative Energy Demand (CED) to vary from 10.1 to 22.6 MJ which is in accordance to the results found by Cesari et al. (2017) for the same stage, and Ozone layer Depletion Potential (ODP) to fluctuate between 77.7 and 238 μg CFC-11 eq and feed and energy had the largest contribution. These results were significant lower than those obtained by Kalhor et al. (2016) during the broiler production. Furthermore, AP results were between 52.9 and 68.4 g SO_2 eq, higher than those obtained by Cesari et al. 2017 for heavy broiler (19.2 g SO_2 eq) and Kalhor et al. (2016) (29.58 g SO_2 eq). EP results varied from 1.39 to 1.43 g PO_4 eq in the farm gate, lower than those found by Kalhor et al. (2016) (11.2 g PO_4 eq) during the broiler production in the farm.

In addition, Skunca et al. (2018) estimated the GWP in the slaughterhouse gate to fluctuate from 0.28 to 0.63 g CO_2 eq, which was in line with the results obtained by Katajajuuri (2007). Also, for the slaughterhouse gate CED ranged between 5.79 and 13.1 MJ, lower than those calculated by Cesari et al. (2017) and the majority of the studies in the field (Skunca et al. 2018). AP results varied from 7.07 to 17.8 g SO_2 eq, lower than those estimated by Cesari et al. (2017) (29.2 g SO_2 eq) and Kalhor et al. (2016) (41.75 g SO_2 eq). EP results were between 0.19 and 1.86 g PO_4 eq in the slaughterhouse gate. These results were in accordance with those calculated by Da Silva et al. (2012) (1.5 and 1.6 g PO_4 eq). In case of the retail store stage the results obtained by Skunca et al. (2018) regarding the GWP and CED were similar to those estimated by Katajajuuri (2008).

2.2.2. Pork Production

Pig meat is one of the most popular products in the world, with a share of 112.4 million tons of pig meat to be consumed globally, in 2012 (McAuliffe et al., 2016). Worldwide pig meat production associated with the creation of fewer greenhouse gases in comparison with the production of beef and lamb, but more than the production of poultry. CO_2 emissions which are emitted by the combustion of fossil fuels, CH_4 emissions from manure management and enteric fermentation of ruminants and N_2O emissions because of the application of fertilizers, are the main GHGs related to pig sector (Reckmann et al., 2013).

In this literature review five studies which assessed the pig meat production through LCA have been chosen to ascertain the environmental hotspots. This review encompasses the following production systems: One production system following the farrow-to-finish operations, and another based on grow-to-finish operations (Bava et al., 2017). One more production system characterized by the traditional linear pork chain in Catalonia involving companies like feed factories, pig farms, slaughterhouses and cutting facilities (Noya et al., 2017). Also, there is a production system for intensive rearing of pigs, in which animals were reared in sections to gain the appropriate weight before they are led to slaughterhouse (Gonzalez-Garcia et al., 2015). Furthermore, a conventional system is contained in this review based on a variety of ingredients such as wheat, barley and soybean meal (Reckmann et al., 2013). Last but not least, there are three contrasting pig production systems. A conventional production system (GAP) being optimized as regards fertilization practices, a red label system (RL) which is equivalent to the "Pork Fermier Label Rouge" quality label, and an organic agriculture (OA) which follows the European rules for organic animal and crop production (Basset-Mens & Van der Werf, 2005).

Table 2: List of selected LCA studies.

Study	Sample	Research Focus	Functional Unit	System Boundaries	Impact Coverage[a]
Pork					
Bava et al. (2017)	6 farms in Italy	LCA of Heavy Pig Production	Kg live weight	Farm	GWP, EP, AP, TE, EU, LO, RD, OD
Noya et al. (2017)	Feed factories, pig farms, slaughterhouses, cutting facilities in Catalonia	LCA of traditional linear pork chain	Kg cut pork	Feed Production, Farm, Slaughtering, Cutting	CC,TA, FE, ME, WD, FD
Gonzalez-Garcia et al. (2015)	Pig farms and Slaughterhouses in Portugal	LCA of Intensive Rearing of Pigs	kg pigmeat-carcass weight	Feed production, Farm, Slaughtering	CC, FD, FE, FEU, HT, MEU, OD, POF, TA, TE, WD
Reckmann et al. (2013)	A feed factory and a Slaughterhouse in Germany	LCA of pork production	kg slaughtered weight	Feed Production, Farm, Slaughtering	GWP, AP, EP
Basset-Mens & Van der Werf (2005)	Production systems of pig in France	LCA of 3 different pig production systems	Kg live weight	Farm	CC, EP, AP, TT, EU, LO, PU

[a] Impact Coverage: Global Warming Potential (GWP), Eutrophication Potential (EP), Acidification Potential (AP), Terrestrial Ecotoxicity (TET), Energy Used (EU), Land Occupation (LO), Resource Depletion (RD), Ozone Depletion (OD), Climate Change (CC), Terrestrial Acidification (TA), Marine Eutrophication (ME), Fossil Depletion (FD), Freshwater Ecotoxicity (FE), Freshwater Eutrophication (FEU), Human Toxicity (HT), Marine Eutrophication (MEU), Ozone layer Depletion (OD), Photochemical Oxidant Formation (POF), Terrestrial Acidification (TA), Terrestrial Toxicity (TT), Water Depletion (WD), Pesticide Use (PU)

2.2.2.1. Comparison of LCA studies

Similar to chicken production, studies examined the environmental performance of pig production systems showed that the most impactful phase in CC is the crop and feed production (Reckmann et al., 2013; Gonzalez-Garcia et al., 2015; Noya et al., 2017). According to Reckmann et al. (2013) feed production had the strongest impact on GWP with a share of 63% of total value, as well as in the category of Energy Used (EU) was responsible for 92% of total consumption, while pig housing and slaughtering had minor contribution. In line with these results were, Gonzalez-Garcia et al. 2015, having estimated that crop and feed production contributed 86% to the overall value of CC potential and was the main contributor in Fossil Depletion (FD) potential with a share of 88% while animal production system contributed to 7% of FD potential. In contrast, Noya et al. 2017 indicated that, husbandry stage was responsible for large amounts of energy used contributing 45% of FD potential.

It is important to mention that, Gonzalez-Garcia et al. (2015) highlighted that greenhouse gases such as CO_2, N_2O and CH_4 are responsible for CC with a contribution of 57%, 32% and 11%, respectively. CO_2 and N_2O are released from agricultural practices such as the cultivation of wheat, barley, maize and soybean and CH_4 emissions derived from slurry management and enteric fermentation (75%). Therefore, as mitigation process was proposed the replacement of soybean with other alternative sources of protein. Moreover, the development of alternatives for valorization of the organic waste derived from farm activities to produce energy and feed is considered crucial (Gonzalez-Garcia et al. 2015).

The results estimated by Bava et al. (2017) taking into account the impact categories listed in table 2 are comparable with the other selected studies. More specifically, the production of heavy pigs had higher environmental impacts per kg live weight than the production of pigs slaughtered at lighter weight. Particularly, the average GWP was 4.25 ± 1.03 kg CO_2 eq per kg LW, for finishing pigs (100-170 kg Breeding weight). This value is lower than those found by Noya et al. (2017) (4.96 kg CO_2 eq per kg of cut pork), but higher than those obtained by Basset-Mens & Van der Werf (2005) (2.30 kg CO_2 eq for GAP, 3.46 kg CO_2 eq for RL and 3.97 kg CO_2 eq for OA) and Gonzalez-Garcia et al. (2015) (3.34 kg CO_2 eq), which examined the environmental impacts of pigs with lower slaughter weight.

Also, according to Bava et al. (2017) the average of EP was 25.2 ± 5.19 g PO_4^3 eq per kg live weight, which is accordance or slightly higher with those estimated by Basset-Mens & Van der Werf (2005) (16.6 g PO_4^3 eq for LR, 20.8 g PO_4^3 eq for GAP, 21.6 g PO_4^3 eq for OA) and Reckmann et al. (2013) (23.3 g PO_4^3 eq). Moreover, AP was 32.7± 7.47 g SO_2 eq, which is similar to those obtained by Basset-Mens & Van der Werf (2005) (22.6 g SO_2 eq for RL, 0.0372 g SO_2 eq for OA and 0.0435 g SO_2 eq for GAP), but lower than those found by Reckmann et al. (2013) (57.1 g SO_2 eq). Regarding the EU its average was 23.5 ± 6.84 MJ, similar but slightly higher than those estimated by Basset-Mens &

Van der Werf (2005) (22.2 MJ for OA, 17.9 MJ for RL and 15.9 for GAP). Lastly, the average of Terrestrial Toxicity (TT) was 9 g 1.4-DB eq as obtained by Bava et al. (2017), which was lower than those calculated by Gonzalez-Garcia et al. (2015) (22.83 g 1.4-DB eq). Concerning the ODP Bava et al. (2017) estimated that its average was 0.323 ± 0.08 mg CFC-11 eq per kg live weight, which is lower than those found by Noya et al. (2017) (0.66 mg CFC-11 eq), but higher than those obtained by (Gonzalez-Garcia et al. 2015) (0.125 mg CFC-11 eq). As pointed out by Gonzalez-Garcia et al. (2015) the feed production was the main contributor in the ODP.

It is worth mentioning that, the differences in the results could be attributed to several reasons such as, different production systems of animals, the feed used, feed conversion ratio of finisher pigs, the conducted sensitivity analysis and the varying handling of the slaughtering process (De Vries et al., 2015; Dick et al., 2015).

2.2.3. Beef Production

Beef is an important protein source with a high global demand which is expected to increase due to population growth and rising incomes and urbanization (De Vries et al., 2015). Beef production has a serious impact on the environment, accounting for 41% of the total global emission GHGs released through livestock production. Additionally, beef production is responsible for land degradation and deforestation (De Vries et al., 2015). To select the most sustainable practices related to beef production, few studies exist in the field assessing the environmental performance of several beef production systems through LCA methodology (Nguyen et al., 2010).

Six studies have been selected which evaluated the beef production through LCA to determine the environmental hotspots. These studies encompass the following production systems: A typical extensive system be related to grazing cattle feeders, and one typical intensive system, in which beef is produced on feedlots (Huerta et al., 2016). Tsutsumi et al. (2018) carried out a research contained organic, non-organic grass-fed beef production systems and the conventional Japanese system, in which all cattle were managed in barns except from the period from mid-May to mid-October in case of organic and non-organic systems, in which cattle were grazed on pastures (Tsutsumi et al., 2018).

Furthermore, another study carried out by Dick et al. (2015) included two typical beef cattle production systems, the extensive system (ES) and the improved system (IS). The ES is characterized by the use of large tracks of land, where the animals graze on the natural pasture during the year. The IS is featured by lower impacts of seasonal grassland production of native pastures with increased forage production and feed quality (Dick et al., 2015). Furthermore, Ogino et al. (2017) conducted a study examining a beef cow-calf system the main characteristic of which is that the calves and cow were fed in a barn. Additionally, Nguyen et al. (2010) evaluated three beef production systems from intensively reared dairy calves and one from suckler herds. The three dairy calves systems differed concerning the quantity of concentrate used, the amount of land used as well as the age of the animals led to slaughterhouse. Also, this system has as main feature the combination of outdoor grazing in the summer and indoor feeding with grass silage and concentrates in winter. The suckler herds system is characterized by the medium slaughter age of calves and an artificially rearing in the dairy herd (Nguyen et al. 2010).

Table 3: List of selected LCA studies.

Study	Sample	Research Focus	Functional Unit	System Boundaries	Impact Coverage[a]
Beef					
Tsutsumi et al. (2018)	Yakumo Farm in Japan	LCA of 3 beef production systems	Kg carcass weight	Farm	GWP, AP, EP, EU
Tichenor et al. (2017)	Grass-fed beef and confinement dairy beef production systems in Northeastern U.S	LCA of 2 beef production systems	Kg carcass weight	Farm	GWP, AP, EP, LO, FD, WD
Huerta et al. (2016)	Farmers, Slaughterhouses and retail point managers in Mexico	LCA of 2 beef production systems	Kg boneless and fatless beef	Production, Processing, Marketing	CC, HT, TA, FEU, MEU, TE, ALO, WD, FD, POF, FE, ME
Dick et al. (2015)	2 typical beef cattle production systems in Brazil	LCA of 2 beef cattle production systems	Kg live weight	Farm	GWP, LO, TA, FE, FWD, MD, FD
Nguyen et al. (2010)	1 Suckler cow-calf and 3 dairy calf production systems in Denmark	LCA of 4 beef production systems	kg meat slaughter weight	Feed production, Farm	GWP, AP, EP, EU, LO
Ogino et al. (2007)	A beef cow calf system in Japan	LCA of beef cow-calf system	one marketed beef calf	Feed production, Farm	GWP, AP, EP, EU

[a] Impact Coverage: Global Warming Potential (GWP), Eutrophication Potential (EP), Acidification Potential (AP), Energy Used (EU), Land Occupation (LO), Fossil Depletion (FD), Water Depletion (WD), Climate Change (CC), Human Toxicity (HT), Terrestrial Acidification (TA), Freshwater Eutrophication (FEU), Marine Eutrophication (MEU), Terrestrial Ecotoxicity (TE), Agricultural Land Occupation (ALO), Photochemical Oxidant Formation (POF),

Freshwater Ecotoxicity (FE), Marine Eutrophication (ME), Terrestrial Acidification (TA), Freshwater Ecotoxicity (FE), Freshwater Depletion (FWD), Metal Depletion (MD)

2.2.3.1. Comparison of LCA studies

The above selected studies having assessed the life cycle of beef products showed, as the studies of chicken and pork production, that processes taken place during the feed production and animal housing were responsible for the most environmental impacts. Specifically, according to Huerta et al (2016)**,** corn, manure management, fertilizers and enteric fermentation were the main contributors to environmental impacts with the cow-calf stage to be the strongest contributor to CC, Terrestrial Acidification (TA), Freshwater Eutrophication (FEU), Marine Eutrophication (MEU), and Agricultural Land Occupation (ALO). The values of CC were 19.3 and 21 kg CO_2 eq per kg of beef, in the IS and ES, respectively, which were similar to those obtained by Dick et al. (2015), who found 9.16 and 22.52 kg CO_2 eq per kg of beef, in two typical beef production systems, the one with the improved pasture and the other with natural grass. Also, according to Huerta et al. (2016)**,** the TA potential was 0.79 kg SO_2 eq/kg meat in the IS, while in the ES was 0.57 kg SO_2 eq/kg meat. These values were higher than those obtained by Nguyen et al. (2010), who calculated a total value of 0.101 and 0.210 kg SO_2 eq per kg carcass weight in the dairy calves systems and suckler herds system, correspondingly. This difference could be attributed to the methodology used in studies as well as the fluctuation of the time to be gained the final weight (Huerta et al., 2016; Nguyen et al., 2010).

Tsutsumi et al. (2018) pointed out that the major contributor in GWP for all three examined systems was enteric fermentation during the animal housing, followed by the excreta in the organic system and roughage production in the non-organic system. In this study the GWP was 29.3 kg CO_2 eq/kg of cold carcass weight in case of organic system, similar to those obtained by Nguyen et al. (2010), who estimated 27.3 kg CO_2 eq/kg meat slaughter weight in the suckler cow-calf system. In the non-organic system the CO_2 emissions were 35.1 eq/kg of cold carcass, higher than those found by Nguyen et al. (2010). The AP was 115.9 and 103.5 g SO_2 eq/ kg of cold carcass weight, in the organic and non-organic system, respectively, lower that those obtained by Nguyen et al. (2010), who calculated 210 g SO_2 eq/ kg carcass weight.

Tichenor et al. (2017) estimated that GWP was 33.7 kg and 12.7 kg CO_2-eq per kg hot carcass weight in the GF and DB, respectively. In case of GF the major contributor of GHGs was CH_4 emitted from enteric fermentation with a share of 57%, followed by N_2O emissions from grazed pastures. For DB, the main contributor was again enteric methane with a share of 37%. Also, corn grain was the second contributor responsible for 9% of system emissions (Tichenor et al., 2017). The GWP in the DB was lower than those obtained by Nguyen et al. (2010), who estimated the CO_2 emissions to range from 16 to 19.9 kg CO_2-eq per kg meat in the dairy calves systems. Additionally, DB had higher AP and EP impacts than GF, because of phosphorus and nitrate losses from feed and crop production (corn silage, grain production) with a share of 86% of total emissions (Tichenor et al., 2017). In this study EP was 184.8 and 75.6 g PO_4^{3-} per kg hot carcass weight for GF and DB, correspondingly. Likewise, Nguyen et al. (2010) found the EP potential to be 73.7 g PO_4^{3-} per kg carcass weight in the dairy beef system in which dairy bull calves raised to 16 months.

Dick et al. (2015) found the total CO_2 emissions to be 18.32 and 45.05 kg CO_2 eq in the IS and ES system, respectively. Nguyen et al. (2010), obtained an intermediate value for the suckler herd systems (27.3 kg CO_2 eq/kg meat slaughter weight). According to Dick et al. (2015), TA was 0.0028 and 0.0038 kg SO_2 eq/kg live weight for the ES and the IS, correspondingly. These values were different to those estimated by Ogino et al. (2007) in Japan (0.248 kg SO_2 eq/kg LWG) and by Nguyen et al. (2010) in Europe (0.1 kg kg SO_2 eq/kg LWG). Moreover, Dick et al. (2015) calculated Freshwater Ecotoxicity (FE) to be 0.00383 and 0.00219 kg P eq/kg LWG, in the ES and IS, respectively, which are different to those obtained by Ogino et al. (2007) in Japan (0.0431 kg P eq / kg LWG). These variations in studies could be attributed to different local soil and climatic conditions and other features inherent to production systems which makes the comparison between studies to be difficult (Dick et al., 2015).

In addition, it is important to mention that the suckler cow calf system examined by Nguyen et al. (2010) in Europe consumed significant lower amount of non-renewable energy than the cow-calf system examined in Japan by Ogino et al. (2007) (59.2 MJ/ kg meat versus 169 MJ/ kg LWG). This can be explained as the Japanese cow-calf system consumes larger amount of energy due to the longer residence time for growing and fattening as well as the energy cost for the transportation of feed in long distances (Ogino et al., 2007).

2.2.4 Comparison of Greek & Portugal Broiler Production

The food sector is one of the most prominent manufacturing and economic sectors in Europe, with a share of 14.5% of the total manufacturing turnover (Gonzalez-Garcia et al., 2014). Especially, chicken meat production has the highest demand after the beef production in Europe (Magdelaine et al., 2008). It is worth mentioning that, broiler chicken represents 75% of the total meat consumption in Portugal. In case of Greece, it is crucial the weaknesses related to Agricultural Sector to be handled and its competitiveness to be improved (Bartzanas et al., 2015). Therefore, it is important for both counties to find sustainably production and consumption in terms of food products. As detailed below, a comparison of two chicken production studies implemented in Portugal and Greece took place for a better understanding of its efforts to deal with the environmental burdens arise from meat production.

Giannenas et al. (2017) conducted an LCA approach to evaluate the environmental performance of the broiler production systems related to the proposed diets scenarios. The study was carried out in a group of broilers raised on a commercial Greek farm and chicks were equally divided into three dietary treatments. The first group was characterized by a conventional diet of corn and soybean meal, containing 21% w/w crude protein. The second group was based on corn and soybean meal containing 20% w/w crude protein and 200 mg of protease (Ronozyme Proact) per kg of feed. The third group was characterized by the absence of soybean ingredients, having as main constituents the corn and corn gluten meal as well as 20% w/w of crude protein and 200 mg of protease (Ronozyme Proact) per kg of feed. The system boundaries for the examined partial life cycle of the production of 1 kg of broilers' Live Weight (LW), included all process associated with the feed and crop production as well as the rearing of the broilers. The LCA results showed that the second and third group had better environmental performance than the first group (Giannenas et al. 2017).

Gonzalez-Garcia et al. (2014) evaluated the life cycle of broiler chicken production from a cradle-to-slaughterhouse gate perspective through LCA method. The life cycle inventory data were collected from a farm and a slaughterhouse of a broiler-chicken company in Portugal. The SB contained all procedures associated with the chicken farm and the slaughterhouse until the meat product to be delivered in the stores. The feed included ingredients such as wheat, maize, soybean oil, soybean cake, protein concentrate, monocalcium phosphate and fats. The functional unit was selected as 1.2 kg of broiler chicken meat ready to be delivered to the point of sale. The results showed that feed production and on-farm emissions were responsible for the most environmental impacts. Also, regarding the slaughtering stage, the production of electricity and packaging materials were the main contributors to impact categories (Gonzalez-Garcia et al., 2014).

Gonzalez-Garcia et al. 2014 indicated that GWP was 2.7 kg CO_2 eq for chicken farm stage, which is in the range of those obtained by Giannenas et al. (2017) (1.63-4.21 kg CO_2 eq). Furthermore, according to Gonzalez-Garcia et al. 2014, AP and EP were 51.9 g SO_2 eq and 24.4 g PO_4^{3-} eq, correspondingly, higher than those calculated by Giannenas et al. (2017) (28.7-32.4 g SO_2 eq and 17.5-17.8 g PO_4^{3-} eq, respectively). Moreover, in case of CED the value ranged from 14.67 to 15.39 Mj concerning the study implemented by Giannenas et al. (2017), while the CED estimated by Gonzalez-Garcia et al. 2014 was 18.6 Mj. Last but not least, the ADP was calculated 8.5 g Sb eq by Gonzalez-Garcia et al. 2014, on the contrary with those obtained by Giannenas et al. (2017) (0.001-0,00151 g Sb eq). The differences in both studies could be attributed to differences in systems evaluated and LCA methodology implemented such as variations in broiler rations, characterization factors and emission factors. In addition, data quality, system boundaries as well as rearing scenarios played a significant role in the variation between the results (Gonzalez-Garcia et al., 2014; Giannenas et al., 2017).

To conclude, both studies highlighted that feed and crop production was the main contributor to environmental impacts. The contributions to impact categories are related to the production and use of fertilizers to produce feed ingredients (Gonzalez-Garcia et al., 2014). For this reason, it is important all stakeholders to find solutions to be dealt with this environmental hotspots. Therefore, Gonzalez-Garcia et al., 2014 proposed improvement actions such as the use of manure to agricultural land as organic fertilizer replacing with this way the mineral fertilizers as well as the use of grain legumes instead of soybean due to the cultivation of grain legumes take place without mineral fertilizers. Additionally, Giannenas at al. (2017) implementing experiments on dietary scenarios characterized by the reduction of soybean ingredients, indicated that the reductions in environmental impacts are attributed to the complete substitution of soybean and the increase of corn use. Therefore, they suggested that the Gluten-Prot diet would be an ecofriendly solution if water depletion for the production of corn and wheat decreased and if electricity production in Greece was not in a high level dependent on the lignite.

2.3. Regulatory Framework

It is crucial all meat companies to comply with European regulation, strategies and policies in order to improve its environmental performance and enhance its contribution to sustainable development. In the following sections, a description of the most important European Regulations carries out, followed by the Greek legislation.

2.3.1. European Legislation

COUNCIL DIRECTIVE 98/58/EC

The council of the European Union has adopted the Directive 98/58/EC which has applied since 8 August 1998 and European countries had to incorporate it into the national law by 31 December 1999. This directive establishes minimum standards regarding the protection of animals risen or kept for farming purposes such as the protection of foodstuffs, wool, fur or skin (European Commission, 2018).

According to European Commission, 2018 the Directive 98/58/EC requires European countries to adopt rules guarantying with this way that keepers or owners of animals care for the welfare of their animals which are kept without pain or any other form of injury. The rearing conditions cover several parameters depending on past established experience and scientific knowledge. These breeding conditions are the following:

- *Staffing:* All animals have to be cared by specialized staff.
- *Inspection:* Animals must be inspected at least once a day in their husbandry systems

- *Record keeping:* It is necessary all keepers or owners of animals to keep a record regarding any medical treatment.
- *Freedom of movement:* In all animals must be given appropriate space for movement.
- *Buildings and Accommodation:* Materials related to construction of accommodation of animals must be capable of being cleaned and disinfected. Parameters such as air circulation, dust levels, temperature and relative humidity have to be kept within the limits.
- *Automatic or mechanical equipment:* This equipment have to be inspected in daily basis.
- *Feed, Water and other substances:* All animals must be fed with appropriate diet in regular intervals.
- *Mutilations:* It is necessary national regulation on mutilation to be applied.
- *Breeding Procedures:* Each rearing procedure that may harm the animals must not be implemented.

The competent national authorities of each European country must conduct inspections and report on these to the European Commission. Lastly, every five years the Commission has to report to the Council regarding the implementation of the Directive 98/58/EC providing proposals for improvement if it is required (European Commission, 2018).

COUNCIL REGULATION (EC) No 1/2005

The council of the European Union has adopted the Regulation (EC) No 1/2005 which applies from 25 January 2005. The purpose of this regulation is to protect the animals during transport and related activities. In particular, this rule regulates the transport of animals that take place within the Europe and makes provision for the appropriate inspections conducted in the animals entering or leaving the European countries (European Commission, 2018).

The principal requirements regarding the transportation of the animals have as a result the safe movement in their destination. First of all, during the journey the most optimal route must be followed to minimize its length keeping the animals in a good condition. The means of transport and the related facilities have to be constructed and maintained so as the safety of the animals to be ensured. Moreover, the staff must be appropriate trained to deal with the animals checking for their continuously welfare and providing them with feed, water and rest when it is necessary (European Commission, 2018).

Regarding the transporters, it is important to have an authorization from the relevant national authority for all journeys over 65 km as well as to possess detailed documentation concerning information about the animals such as their origin, ownership and destination. Furthermore, national authorities have to inspect the transport facilities before they are used for long journeys as well as to require from the transporters to be based in an Europe country. Additionally, transporters have to display that they have adequate and suitable staff, equipment and operational procedures without record of breaking the law regarding animal protection during the previous three years. In case of journeys between European countries and destinations outside the Europe, it is crucial transporters have the required authorization, documentation, satellite navigation system and plans for emergencies. Last but not least, if an emergency happen the national authority must take the appropriate measures for rapprochement (European Commission, 2018).

COUNCIL REGULATION (EC) No 1099/2009

The council of the European Union has adopted the Regulation (EC) No 1099/2009 which applies from 1 January 2013. The purpose of this regulation is to bring in rules regarding the welfare of the animals during killing or slaughter for the production of food and products as well as the killing of animals on farm to prevent epidemic diseases. Particularly, the regulation specifies detailed rules about restraining and stunning animals, containing the appropriate training of the staff as well as the appropriate maintenance of equipment covering the application of different methods for different kind of animals (European Commission, 2018).

According to the Regulation (EC) No 1099/2009 the operators that take on the killing of the animals must have the appropriate abilities to do so and in some procedures certification about their abilities must be displayed. For instance, in cases of handling and care of animals before they are restrained as well as slaughtering conforming to religious practices, certification is required. Also, certificate regarding the health of animal imported from non-European countries have to confirm that the prerequisites have been met (European Commission, 2018).

The Regulation (EC) No 1099/2009 establishes detailed rules regarding the construction, the equipment and operations of slaughterhouses. All processes take place in a slaughterhouse must be monitored by operators and the Animal Welfare Officer have to take action ensuring the compliance with this regulation. It is important to note that, in case of emergency killing for the prevention of diseases an action plan must be exist so as the compliance of this law to be ensured. The report have to include the reasons for the emergency slaughtering, the number and the species of the animals which were killed as well as the stunning and killing methods carried out. Last but not least, European countries must ensure that rules established by this regulation are implemented and the competent authorities can occur more frequently inspections as well as withdraw certificates of competence if it is needed (European Commission, 2018).

COUNCIL REGULATION (EC) No 834/2007

The council of the European Union has adopted the Regulation (EC) No 834/2007 which applies from 1 January 2009. The main purpose of this directive is the organic production as well as labelling of organic products. Therefore, basic objectives and general principles regarding the organic farming as well as rules on the production, labelling, controls and trade with non – European countries, are contained in this regulation. Agricultural products for human consumption, animal feed, vegetative propagating material and seed used for crops as well as yeasts used as food or feed, are the categories of products included in the Regulation (EC) No 834/2007 (European Commission, 2018).

Concerning the livestock production have to meet requirements in order to be in compliance with this regulation. For instance, concerning organic livestock production the animal's origin must be taken place in organic holdings. Moreover, animal breeding procedures must be natural and animal feed have to be organic. Furthermore, cleaning and disinfection must be carried out with products authorized by the Commission. In addition, the Commission permits the usage of a limited number of products and substances in organic farming. Organic raw materials have to be included in organic processed feed without the use of chemical solvents (European Commission, 2018).

It is worth mentioning that, in order to be described an organic product, its ingredients or raw materials, terms such as "eco" and "bio" have to be used. The usage of the European logo on organic food products has been mandatory since 1 July 2010. Compliance with this regulation is guaranteed by the Regulation (EC) No 882/2004 as well as protective and control measures drafted by the Commission. Also, this system assures the traceability of food as stipulated by Regulation (EC) No 178/2002. Last but not least, products entered from non – European countries, which be in compliance with this Regulation after the implementation of appropriate control, maybe sold in the Europe market as organic products (European Commission, 2018).

2.3.2. Greek Legislation

Law 374/2001

The Greek regulatory framework that defines the protection of animals risen or kept for farming purposes is in accordance with the development of the European Directive 98/58/EC regarding the animal protection. Specifically, the Law 374/2001 incorporates the articles 1, 2, 3, 4, 6 and 7 and the annex of the Directive 98/58/EC establishing the minimum standards regarding the protection of animals in farms, in implementation of the Directive 2000/5/EC "amending Annexes C and D to Council Directive 92/51/EEC on a second general system for the recognition of professional education and training to supplement Directive 89/48/EEC" (e-nomothesia.gr, 2018).

Law 4056/2012

The Greek Parliament has passed the Law 4056/2012 regarding the settings for husbandry and livestock facilities and other ordinances. The main purpose of this Law is to display the requirements for the operational qualification of the livestock units. In particular, the law categorizes the livestock facilities in four categories depending on the kind of buildings as well as their intensity. These are the simple animal accommodations for which no building permit is required, animal facilities for which building permit is required, animal facilities which are occupied over than 300 m^2 as well as those which are manufactured in accordance with approved types of animal shelters with greenhouse frame. Moreover, this law records the permitted positions for the livestock installations, the limited size of areas that have to be occupied by animals units, the minimum distances between livestock facilities as well as the method of measuring them. Furthermore, the Law 4056/2012 concerns the procedure in order to be given permit for the establishment of livestock units as well as the modification or transfer of livestock installations permits. Additionally, the registry of the livestock facilities as well as the requirements for their existence in woodland areas are two another article of this law. Latest updates regarding this Law are included in the Law 4424/2016 of 2016 (e-nomothesia.gr, 2018).

Law 79/2007

The Greek Parliament has passed the Law 79/2007 which applies from 3 May 2007. This Law concern the necessary complementary measures for the implementation of Regulations (EC) 178/2002, 852/2004, 853/2004, 854/2004 and 882/2004 which have been adopted by the European Parliament and Council regarding the hygiene rules for food produced from animals, official inspections on products intended for human consumption, animal health and welfare rules as well as harmonization of the veterinary legislation to Directive 2004/41/EC which has voted by the European Parliament and Council (e-nomothesia.gr, 2018).

The Law 79/2007 includes the recording of the reasons which determine the frequency that official inspections have to take place in food production companies in order to be in compliance with rules concerning the health and welfare of animals. Moreover, procedures of measures enforcement in cases of non-compliances are quoted in article 13. It is important to note that, the article 15 of Law 79/2007 points out that during the official inspections conducted by the Veterinary Authorities, the procedures regarding the appropriate transportation, slaughter and killing of animals, appropriate breeding practices, right pre-manufacture processes, suitable hygiene procedures as well as the HACCP system according to article 4 of the Directive (EC) 854/2004, are evaluated in collaboration with Competent Authorities when it is necessary (e-nomothesia.gr, 2018).

In addition, the Law 79/2007 refers the cases in which a record of the official inspections must be kept by the food companies as well as the duties that a veterinary physician has regarding the maintenance of an official documentation. Moreover, the article 20 of this Law concerns the sampling and analysis of products produced by animals and the articles 21 and 22 concern the Laboratories in which the analysis of the samples are implemented and the National Reference Laboratories, respectively. As far as the transportation of living animals and food produced by animals are concerned, the article 24 of this Law refers that during breeding, transportation and killing of living animals the Council Regulations (EC) 1255/1997 and (EC) 411/1998 as well as the Law 327/1996 which in accordance with the Council Regulation (EC) 93/119/EC are implemented. Last but not least, the article 29 concerns the penalties for non-compliance with the purpose of this Law. It is worth mentioning that, amendments regarding this Law are incorporated in the Law 4472/2017. Also, latest updates exist in the Law 4558/2018 (e-nomothesia.gr, 2018).

3. Methodological Framework

This chapter includes all necessary information about the LCA method, which applied in this study and the data needed for the detailed assessment of the environmental potentials by meat production in a specific Greek Meat Company.

3.1. Life Cycle Assessment

In the recent years, companies have been developed searching for practices or methods to outclass among their competitors. One way to achieve this is the adoption of procedures which contribute to sustainable development making companies to be more competitive (Da Luz et al., 2018). For instance, a movement towards more sustainable products is a significant aspect of sustainability (Moreno et al 2011). In this context, sustainability is a requirement for competitive companies which continuously try to find solutions concerning the impacts related to their products from the development until the disposal stage (Lacasa et al., 2016).

It is worth mentioning that, product development presents few challenging issues that society is facing the 21st century industry (Da Luz et al., 2018). According to Da Luz et al 2018, these challenges are the following:

- global competition
- rapid changes in customer expectations
- the socioeconomic environment
- accelerated technological innovation decreasing the product life cycle
- cultural aspects
- government restrictions regarding unsustainable products

To deal with these important challenges and more specifically with those that address sustainability issues, environmental factors have been taken more attention concerning processes that related to product development (Telenko et al., 2016). For this reason, in the literature there are two different types of tools which assess the environmental impacts caused by products and industrial procedures. Firstly, the procedural tools such as Environmental Impact Assessment, Risk Assessment and

Technological Assessment which focus on the processes and the connections to their social and decision-making context. Secondly, the analytical tools like Life Cycle Assessment (LCA) and Ecological Footprint (EF) methods which focus on technical aspects of the analysis (Reckmann et al., 2012).

3.1.1. Theoretical Model of Methodology

LCA is the collection and interpretation of the inputs, outputs and potential environmental impacts of a product system during its life cycle and a broadly applied tool for the analysis of the environmental load of products at all stages in their life cycle (Skunca et al., 2018; Reckmann et al., 2012). LCA tool emphasizes environmental hotspots in the production chain, helping the stakeholders to find solutions for the reduction of the environmental burdens as well as the improvement of efficiency and profitability (Skunca et al., 2018). The aim of the LCA tool is the comparison of alternative products, procedures or services, the comparison of alternative life cycles for a specific product or system as well as the identification of the parts of the life cycle where the most important improvements can take place (Reckmann et al., 2012).

The LCA is standardized in ISO 14040 and ISO 14044 standards which define an LCA study incorporating of four phases: Goal and Scope Definition, Life Cycle Inventory Analysis (LCI), Life Cycle Impact Assessment (LCIA) and Interpretation (ISO, 2006a, b). These stages are described in the following paragraphs for a better understanding of the LCA implementation.

Goal and Scope Definition: This is the most important part of an LCA study. In this phase, the purpose and limits of the study, the projected application and the intended audience are defined. Moreover, the system boundaries, functional unit and assumptions are selected (Kalhor et al., 2016; Reckmann et al., 2012). The functional unit is defined as a quantified performance of a product system to be used as a reference unit in an LCA study. The purpose of a functional unit is to make a reference to which inputs and outputs are related allowing for comparison of different product systems on a common basis (ISO 2006, b). The system boundary defines which components of a finished system are contained under the evaluation. Therefore, the determination of geographic or temporary limits as well as the exclusion of certain procedures take place (Reckmann et al., 2012).

Life Cycle Inventory Analysis (LCI): In this stage the data collection of the LCA study take place. More specifically, LCI is the collection of the inputs (including raw materials, energy, etc.) and the outputs (including products, co-products and emissions) from the production system throughout its life cycle concerning the defined functional unit (Kalhor et al., 2016; Reckmann et al., 2012).

Life Cycle Impact Assessment (LCIA): According to ISO, 2006a the aim of this phase is to comprehend and assess the magnitude and significance of the possible environmental impacts of the studied system. This stage converts the existing outcome of the LCI phase into potential contributions. Therefore, environmental impacts caused by several factors such as emissions generated by the production system are converted into impact categories (Tiruta-Barna et al., 2007). There are a variety of impact assessment methods that have been used in LCA studies. For instance, some of them are the CML method, Eco-indicator 99, EPS 2000 and Ecological Scarcity. It is important to mention that, the LCIA comprises of several compulsory and optional components. The impact assessment commonly comprise of classification, characterization and valuation components (Kalhor et al., 2016).

Interpretation: In this phase, the interpretation of the results of the LCI and LCIA phases take place. More specifically, the life cycle interpretation phase consists of conclusions and recommendations according to the framework of the goal and scope of the study (ISO, 2006a, b).

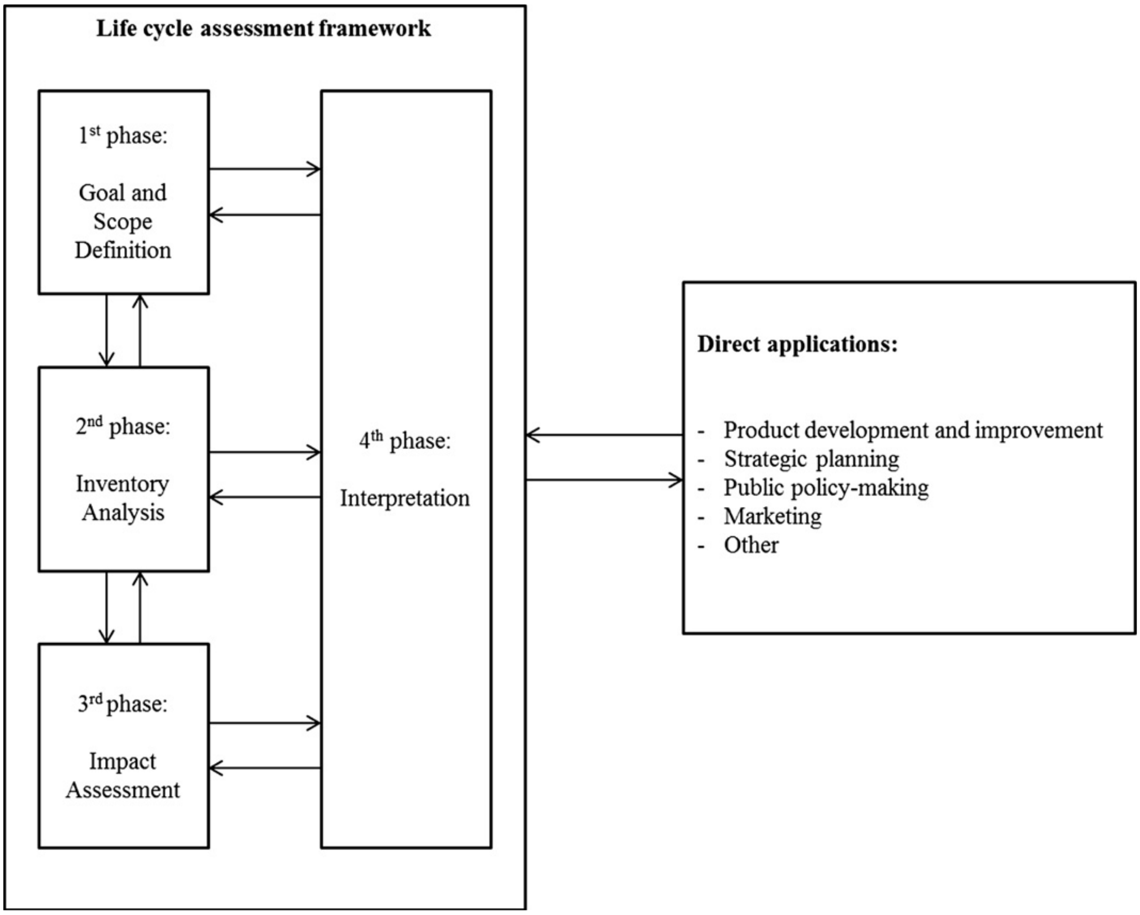

Figure 1: Stages of an LCA (ISO, 2006a, b).

It is worth mentioning that, there are two types of methods for an LCA in the literature, which are the attributional and consequential LCA. Regarding the attributional LCA, this method describes the environmentally related physical flows to and from a life cycle and its subsystems in a status quo situation in the context of the functional unit. On the other hand, consequential LCA quantifies the environmental consequences of a change at the level of the functional units created to illustrate future improvements. The attributional LCA is the more broadly applied method due to it is qualified to recognize environmental burdens in the production chain (Reckmann et al., 2012; Vries et al., 2015).

3.1.2. Limitations of LCA methodology

Although a strong development in LCA methodology has taken place, there are some limitations related to LCA tool. First of all, the excess of data used in the LCA method make difficult the draw of conclusions from a specific case study. Moreover, the selection of different kinds of impact categories in the majority of studies, restricts in some cases the purpose of an LCA which is a comprehensive view of environmental impacts. In addition, the selection of several parameters as well as the assumptions that have been made, may possibly affect the results of the study (Reckmann et al., 2012).

Specifically, regarding the functional unit, the main problem is that it is difficult to compare studies which make use of different functional units. Therefore, in order to compare different case studies, the results have to be counted back on a standardized Functional Unit (Reckmann et al., 2012). In case of system boundary, there are studies which cover the entire production chain, while others have utilized many cut-off rules making difficult the comparison between them (Reckmann et al., 2012; Weidema at al., 2008a).

Another issue in LCA studies is the allocation of co-products due to some procedures shared between several production systems, making difficult the allocation of environmental impacts in certain products (Lundie et al., 2007). According to International Standard, there are three allocation methods, the economic allocation, physical allocation as well as mass expansion. Regarding the economic allocation, the environmental impact of a product or procedure is allocated to its multiple outputs depending on their relative economic value (ISO, 2006b).

Last but not least, the emissions into the environment as well as the consumption of resources can be clarified in relation to impact categories (Gonzalez et al., 2015). The most widely used in LCA studies are the following: global warming potential, acidification potential, eutrophication potential, primary energy use, land use, and abiotic resource use (Williams et al., 2006). In this case the main problems regarding the comparison between studies are attributed to methodological differences related to LCA indicators for selected impact categories per kilogram product. Additionally, the researchers use varying IPCC guidelines, which include a diversity of equivalence factors, restricting the comparison of studies as well (Reckmann et al., 2012).

3.1.3 Sima Pro Software

Sima Pro is one of the most leading software programs used for LCA studies worldwide. It is a product system modeling and assessment software that first appeared on the market in 1990. This software has been developed and distributed worldwide by Pre Consultants, based in Netherlands (Herrmann & Moltesen, 2015). Sima Pro is a professional tool to collect, analyze and monitor the sustainability performance data of a company's products and services. The sustainability reporting, product design, carbon and water footprinting, the determination of key performance indicators (KPI) as well as the generation of environmental product declarations (EPD) are examples of the variety of applications for which the software can be used (Sima Pro, 2018).

The Sima Pro software has been developed in accordance with ISO 14040 and 14044 series standards. Regarding ISO 14040, it considers the principles and framework for an LCA. On the other hand, ISO 14044 specifies the prerequisites and guidelines for the implementation of an LCA study. Sima Pro can analyze and monitor the sustainability performance of products, services and processes through systematic and transparent way. Moreover, it enables the measurement and evaluation of environmental impacts throughout the life cycle, from extraction of raw materials to manufacturing process, use and final disposal. Last but not least, Sima Pro can identify the environmental hotspots across all life cycle stages (Sima Pro, 2018).

3.2. The Case Study of a Specific Greek Meat Company

It is crucial meat companies to be aware of their environmental footprint trying to decrease it when it is necessary. The evaluation of the environmental impacts of a production system in a dairy cattle farm took place through the implementation of the LCA approach. The description of the system under study, the improvement actions proposed as well as the main stages of the LCA method are described in the following sections.

3.2.1. Description of the system under study

The case study was carried out on a typical dairy cattle farm located in Thessaloniki, Greece to collect data from a representative sample of herds. The production system is intensive in which dairy cattle were fed in barns. This system has herd size of 120 heads and the average weight of each dairy cattle range from 550 to 650 kg (kilograms). The dairy cattle are fed with specific amounts of feed in order to produce milk on a daily basis. The diet is mainly based on corn grain, wheat grain, soybean meal, wheat straw, sunflower meal as well as maize silage. The latter is produced in the dairy cattle farm under study while the other feeds are imported from other cities in Greece. The daily production of milk from each dairy cattle is 30 liter.

It is worth mentioning that, nitrogen (N) and phosphorus (P) are basic chemical elements in dairy cattle nutrition. Nevertheless, the majority of them is excreted through biological procedures having as a result urine and manure derived from dairy cattle to contain a significant amount of N and P, which may cause water eutrophication (Biagini & Lazzaroni, 2018). Therefore, the main feeds used for the breeding of dairy cattle in the farm under study as well as their content of N and P are recorded in the following table.

Table 4: Components of the diet followed in the farm under study as well as their content of N and P.

Feed	Amount(kg)/head/day	CP* (g)	P (g)
Corn grain	2.6	251.14	3.84
Wheat grain	7.2	926.9	10.75
Soybean meal	0.8	395.5	2.13
Wheat straw	4	114.94	0.83
Sunflower	0.7	249.32	2.36
Maize Silage	16	118	19.2

*Crude Protein (CP) is the total amount of N included in the feed.

3.2.2. Description of scenarios

As mentioned in the chapter 2, beef production has the greatest environmental impacts among various livestock production systems in comparison with pork and chicken production. Specifically, it can be concluded that, the farming stage as well as the feed and crop production are responsible for the majority of effects on the environment. It is worth mentioning that, the valorisation of by-products derived from animals can offer many advantages in the environment and human health (Gonzalez-Garcia et al., 2015). Not only the utilization of by-products produced during the stages of farming or slaughtering can improve the environmental performance of a meat industry but increase its economic benefits as well. In this study, the LCA methodology will be applied in order two compare two different scenarios described in the following paragraphs.

1st scenario: *Intensive system without valorisation of animal by-products*

This scenario represents those that corresponds to the present situation in the dairy cattle farm under study. As mentioned before, the production system is intensive and the dairy cattle were managed in barns in order to produce milk for consumption. The valorisation of the produced slurry does not take place within the farm.

***2st scenario*:** *Intensive system with valorisation of animal by-products* – Alternative scenario

This scenario models the intensive system that take place in the dairy cattle farm under study with the valorisation of manure produced by animals. More specifically, the improved practices are the following:

- Anaerobic Digestion of dairy cattle manure for biogas production (electricity, heat). Thus, significant amounts of electricity imported from the national grid can be avoided.
- Utilization of the digested manure as organic fertilizer to substitute N and P used for feed and crop production.

After the implementation of the LCA methodology for scenarios 1 and 2 a comprehensive overview of the meat company's environmental performance will be achieved as well as the contribution of the improved practices to the environmental impact categories will be shown. The description of both scenarios is shown in the following table.

Table 5: Description of scenarios 1 and 2

Scenarios	Production System	Valorisation of by-products
1	Intensive system, in which dairy cattle were fed in barns	The valorisation of by-products does not take place.
2	Intensive system, in which dairy cattle were fed in barns	a) Anaerobic digestion of animal manure for biogas production b) Utilization of digested manure as organic fertilizer

3.2.3. Application of the LCA methodology to the case study

The implementation of the LCA approach to dairy cattle farm under study will evaluate the environmental performance of the system. Specifically, the detailed inventory data reported in this thesis will be used for the quantification of environmental impacts derived from the rearing of the dairy cattle. This assessment will allow not only the estimation of the environmental footprint per kg of dairy cattle but also the identification of the environmental hotspots in the production chain as well as the assessment of proposed improvement practices for a better environmental performance.

3.2.3.1. Goal and scope definition

The goal of this study is to analyze and compare two different scenarios regarding Greek practices in livestock production. First of all, the strategies that take place in the dairy cattle farm under study are analyzed from environmental point of view through LCA method. Afterwards, an alternative scenario is proposed including several improvement practices and its evaluation is carried out using the LCA approach similarly. Therefore, a better understanding concerning the environmental profile of the two different scenarios will be succeed after the comparison that will be occurred using the LCA methodology.

3.2.3.1.1. Description of Functional Unit

The functional unit is necessary for a better understanding of the results of an LCA study. As mentioned above, the functional unit is defined as a quantified performance of a product system to be used as a reference unit in an LCA study. It forms a common basis that make feasible the comparison of the outcomes derived from alternative processes or services by enabling the normalization of input and output under a reference factor (Reckmann et al., 2012; Gonzalez et al., 2015). In this study, the functional unit was defined as 1 kg of dairy cattle live weight (LW) at the farm gate. This choice is satisfactory to hold the environmental performance of the two different scenarios.

3.2.3.1.2. Description of System Boundaries

In this study, the system boundaries from a cradle-to-farm perspective of the dairy cattle production chain under evaluation are illustrated in figure 2. Therefore, all procedures or activities associated with crop and feed production as well as the dairy cattle rearing to produce the required amount of milk, were considered. Specifically, direct and indirect inputs and emissions arising from the production and processing of feeds and crops as well as the energy sources are included within the system boundaries of this study. Regarding the production of maize silage it take place within the dairy cattle farm under study, while the other feeds are imported. Therefore, the transport activities of imported feeds are taken into consideration. In addition, in case of dairy cattle breeding, the animal management, energy requirements, enteric fermentation, and manure handling as well as its management were considered within the system boundaries. As far as production and maintenance of buildings is concerned, there were not appropriate information so they were not included in the system boundaries.

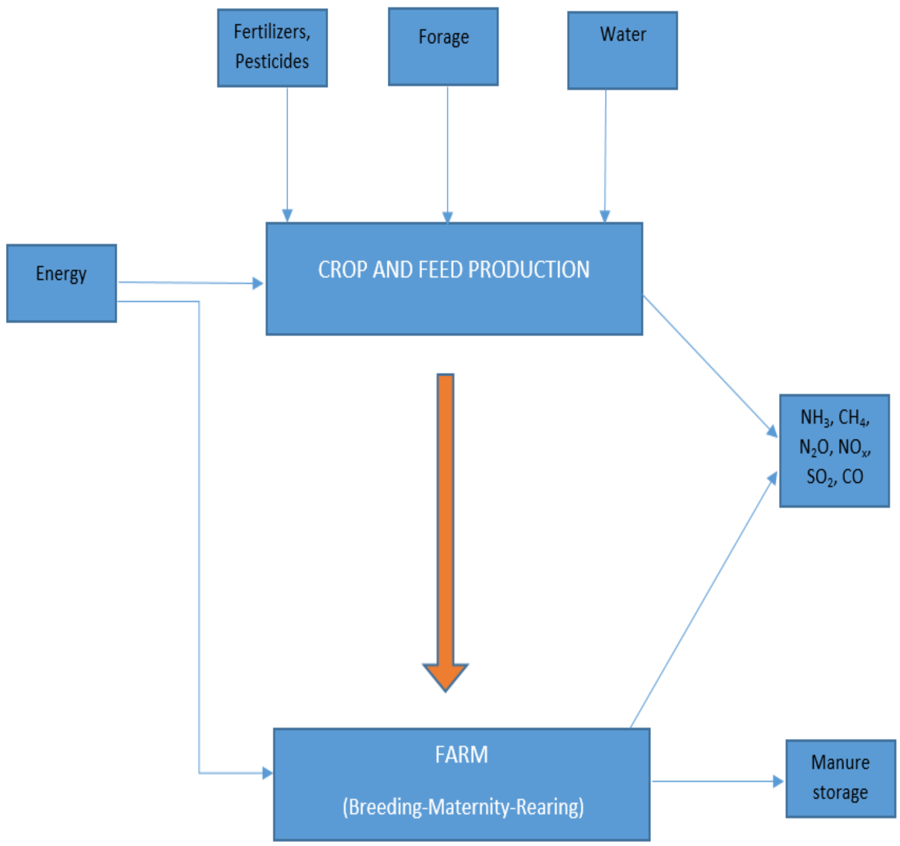

Figure 2: System Boundaries under study

3.2.3.2. Life Cycle Inventory (LCI)

In LCA studies, the collection of real data it is very important in order to obtain real values regarding the environmental results. In the LCA, a specific inventory was created for both scenarios. In this study, the inventory which selected was based on those available in the Ecoinvent database, whereas, particular changes and modifications were introduced only in case that real data concerning the implemented processes were available. More specifically, primary data concerning feed and crop production as well as farming were collected through personal communications with farmers in the representative dairy cattle farm. The most recent data for dairy cattle breeding which correspond to the year 2018 were used. A detailed description of the primary inventory data is shown in the table 6. These inventory data correspond to the functional unit which has been chosen in this study (1 kg LW). The time horizon is 1 year (365 days).

These primary data were completed with secondary data taken from literature to have a more complete estimation regarding the environmental profile of the dairy cattle farm under study. Specifically, required amounts of electricity, production of electricity and heat, avoided mineral fertilizer production and emissions to air and water completed with bibliographic references from other published research papers in this field.

In case of crop and feed production the required amount of electricity was taken form Gonzalez Garcia et al. (2015), while in the case of farming the required amount of electricity was taken from Nguyen et al. (2010). The slurry handling and storage has as a result the release of CH_4, N_2O, NH_3 and NO_x emissions into the air. Concerning CH_4 emissions from enteric fermentation and slurry management were calculated making use of emissions factors reported in IPCC, 2006. Regarding the calculation of CH_4 emissions produced through manure management an assumption was considered. Firstly, the manure in the form of slurry is stored in slurry pits below animal confinements for a period equal to 3.5 weeks. Afterwards, it is transferred to separate slurry tanks where it is stored with a natural crust cover (Nguyen et al., 2010).

Moreover, remaining emissions of NH_3, emissions of N_2O as well as nitrate (NO_3^-) and phosphate (PO_4^{3-}) leaching were calculated using emissions factors reported in Nguyen et al. (2010). In case of scenario 2, the anaerobic digestion of manure has as a result a 90% reduction of CH_4 emissions produced through manure management as well as a 50% reduction of N_2O emissions (Reckmann et al. 2013).

Concerning the avoided amounts of N and P due to the application of digested manure as organic fertilizer in case of alternative scenario, they were calculated according to Gonzalez Garcia et al. (2015). Particularly, the substitution rate for nitrogen is assumed to be 0.7 kg mineral N fertilizer per kg N content in manure applied to soil. In case of phosphorus (P) the substitution rate is 97% (Gonzalez Garcia et al. 2015). Furthermore, the estimation of the N content in manure took place taking into account that 20% of the N content retains in the animals, while the 80% is included in the manure (IPCC, 2006). Regarding the P content, the 83% is contained in manure, while the remainder amount retains in the animals (Nguyen et al., 2010).

Concerning the biogas production through anaerobic digestion in case of alternative scenario, the production of electricity and heat can be estimated according to Nguyen et al. (2011). Specifically, Nguyen et al. 2011 referred that 1.12 kWh produced as electricity /kg VS and 1.45 kWh produced as heat/kg VS. The VS content in dairy cattle slurry was estimated according to IPCC, 2006 with a value equal to 3 kg VS/kg FU/year.

As mentioned above the majority of feeds are imported from other cities in Greece except from maize silage produced within the farm under study. The domestic distances estimated taking into consideration the average distances between possible realistic production sites and the dairy cattle farm and making use of Google maps. A detailed description of secondary data is shown in tables 6, 7, 8 and 9.

Table 6: Primary data inventory per FU (1 kg live weight) for both scenarios.

Inputs	Amount	Unit
Crop and Feed Production		
Forage		
Corn grain	1.58	Kg
Wheat grain	4.38	Kg
Soybean meal	0.49	Kg
Wheat straw	2.43	Kg
Sunflower	0.42	Kg
Maize silage	9.7	Kg
Farm		
Feed	19	Kg
Water	73	L
Outputs		
Feed and Crop Production		
Feed to Farm	19	Kg
Farm		
Finished meat	1	Kg
Manure	20	Kg

Table 7: Secondary data inventory per FU (1 kg live weight) for scenario 1.

Inputs	Amount	Unit	Reference
Crop and Feed Production			
Electricity	0.23	Wh	Gonzalez-Garcia et al. (2015)
Farm			
Electricity	1.07	kWh	Nguyen et al. (2010)
Outputs			
Farm			
Emissions into air			
CH_4	633	g	IPCC, 2006
N_2O	0.48	g	Nguyen et al. (2010)
NH_3	4.8	g	Nguyen et al. (2010)
Emissions into water			
NO_3^-	27	G	Nguyen et al. (2010)
PO_4^{-3}	0.36	G	Nguyen et al. (2010)

Table 8: Secondary data inventory concerning the avoided N and P and the biogas production per FU (1 kg live weight) for scenario 2.

Inputs	Amount	Unit
Crop and Feed Production		
Electricity	0.23	Wh
Farm		
Electricity	1.07	kWh
Outputs		
Feed and Crop Production		
Avoided N	0.7	Kg
Avoided P	0.019	Kg
Farm		
Electricity	3,36	kWh
Heat	4,35	kWh
Emissions into air		
CH_4	204.4	G
N_2O	0.24	G

Table 9: The domestic distances between realistic production sites and the dairy cattle farm.

Feeds	Origin	Transport distance (km)	Means of transport
Corn grain	Greece	70	Truck (<10t)
Wheat grain	Greece	70	Truck (<10t)
Soybean meal	Greece	150	Truck (<10t)
Wheat straw	Greece	100	Truck (<10t)
Sunflower meal	Greece	100	Truck (<10t)

3.2.3.3 Life Cycle Impact Assessment (LCIA)

There are several assessment methods used for environmental impact assessment such as CML 2 Baseline 2000, Eco-indicator 99, EDIP 2003 and EPS 2000. In this study, the CML 2 Baseline 2000 was chosen as an appropriate tool to evaluate the system studied. This impact assessment method is applied by the use of the Sima Pro 7 LCA Software.

According to CML 2 Baseline 2000 the emissions from the conventional and improved system are classified to the following impact categories:

- *Abiotic Depletion Potential (ADP):* It refers to the protection of human well-being and health as well as the ecosystem's health. This impact category indicator is concerned with removal of natural resources such as mineral and fossil fuels and is a relative measure, with the depletion of the element antimony as a reference (kg of antimony equivalents/kg of used materials) (Sima Pro, 2018).
- *Acidification Potential (AP):* Sulfur dioxide and nitrogen oxides emitted in the air from fuel combustion and agriculture have as a result to increase the acidity of rainwater, the known phenomenon as 'Acid Rain' causing changes in the chemistry of soils and water, corrosions to materials and dangers for human health and wildlife. The AP is expressed as kg SO_2 equivalents/kg emission (Lukewille & Alewell, 2008; Sima Pro, 2018).
- *Eutrophication Potential (EP):* It refers to the emissions of nutrients in the water derived from the use of fertilizers in agriculture changing the nutrient composition of them. This has as a result the creation of a biomass formation in waters causing diverse effects in these ecosystems such as the depletion of the dissolved oxygen and harmful algal blooms. This, in turn, affects the ecosystem health and human use. The EP is expressed as kg PO_4 equivalents/kg emission (Wang et al., 2018; Sima Pro, 2018).
- *Global Warming Potential (GWP 100):* This impact category refers to emissions of greenhouse gases emitted by human activities such as fossil fuel combustion, affecting the ecosystem health, human health and material

welfare. The time horizon is 100 years and the GWP is expressed as kg CO_2 equivalents/kg emission (Sima Pro, 2018).

- *Ozone Layer Depletion Potential (ODP):* The cause of ozone depletion in the stratosphere is the increase in the level of detrimental compounds such as chlorofluorocarbons, carbon tetrachloride, halons and methyl bromide. Because of stratospheric ozone depletion, a larger fraction of UV-B radiation reaches the earth surface. This has harmful effects upon human health, animal health, terrestrial and aquatic ecosystems, biochemical cycles and on materials. The ODP is expressed as kg CFC-11 equivalent/kg emission in an infinite time span (Mendez & Rodriguez 2018; Sima Pro 2018).
- *Human Toxicity Potential (HTP):* This impact category refers to impacts caused by toxic substances on the human environment. The HTP is expressed as 1.4 dichlorobenzene equivalents/kg emission and the time span is infinite (Sima Pro, 2018).
- *Fresh Water Aquatic Ecotoxicity Potential (FAETP):* It refers to effects on fresh water ecosystems, because of emissions of toxic substances to air, water and soil. The characterization factors are expressed as 1.4 dichlorobenzene equivalents/kg emission and the time span is infinite (Sima Pro, 2018).
- *Marine Aquatic Ecotoxicity Potential (MAETP):* This impact category concerns effects of toxic substances on marine ecosystems. The characterization factors are expressed as 1.4 dichlorobenzene equivalents/kg emission and the time span is infinite (Sima Pro, 2018).
- *Terrestrial Ecotoxicity Potential (TEP):* It refers to effects of toxic substances on terrestrial ecosystems. The characterization factors are expressed as 1.4 dichlorobenzene equivalents/kg emission and the time span is infinite (Sima Pro, 2018).
- *Photochemical Oxidation Potential (PhOP):* This impact category concerns the formation of reactive chemical compounds such as ozone, by the action of sunlight on certain primary air pollutants. These compounds can cause damages to human health, ecosystems, materials and crops. The POF is expressed as kg ethylene equivalents/kg emission and the time span is 5 days (Sima Pro, 2018).

4. Results and Discussion

The application of LCA tool took place and the results are reported in the following sections. Firstly, the outcomes regarding the scenario 1 are described, followed by the outcomes of scenario 2. Finally, a comparison is displayed concerning the contribution of both scenarios in all impact categories.

4.1 1st Scenario's results

The implementation of the LCA method was carried out in the dairy cattle farm under study. The results showed that the feed and crop production stage had higher environmental impacts than the farming stage in all impact categories. More specifically, in case of GWP the feed and crop production strongly contributed to this impact category with a share of 83% of total contribution, while the rearing of animals represented 17% of the overall GWP. The main gases which are responsible for the GWP are CO_2, N_2O and CH_4 which reflect 57%, 32% and 11% of total GHGs. The production of soybean, maize, wheat and barley is responsible for CO_2 and N_2O emissions produced during agricultural practices. The amount of CH_4 emissions derived from enteric fermentation and slurry management during the breeding of animals is greater than those emitted by feed and crop production (75% and 21%, respectively) (Gonzalez-Garcia, et al. 2015).

The PO_4^{3-}, P and NO_3^- emissions derived from agricultural practices are responsible for the EP. In this study, the feed and crop production stage was responsible for the contributing substances with a share of 94% of total contribution, while the breeding of animals had a share of 6% of total value. Concerning the AP, 92% of total acidifying emissions (sulphates, nitrates and phosphates) were produced from the feed and crop production system. On the other hand, acidifying emissions emitted during the farm stage was responsible for the 8% of total contribution.

In case of ODP, once again the crop and feed production stage strongly affected this category representing the 94% of total contribution, while the rearing of animals reflected the 6% of total value. Regarding PhOP impact category, the NO_x emissions derived from crop and feed production stage were responsible for a share of 79% of total contribution and the farm stage was responsible for the 21% of total contribution. Furthermore, concerning ADP once again the contribution of feed and crop production system was greater with a share of 93%, while the farm stage was responsible for the 7% of total contribution.

In this study, four different toxicity-related categories have been evaluated. The contribution of crop and feed production system in HTP, FAETP, MAETP and TEP was 90%, 91%, 85% and 95%, respectively. The LCA results concerning the environmental impact categories are recorded in the following table and figure.

Table 10: Values of impact categories, according to CML 2000 method

Impact Category	Feed and Crop Production	Farm
Abiotic Depletion (kg Sb eq)	0.0193	0.00151
Acidification (kg SO_2 eq)	0.0514	0.00413
Eutrophication (kg PO_4 eq)	0.0577	0.00344
Global Warming (kg CO_2 eq)	5.09	1.02
Ozone Layer Depletion (kg CFC-11 eq)	3.7 E-7	2.18 E-8
Human Toxicity (kg 1.4-DB eq)	0.919	0.0975
Fresh Water Aquatic Ecotoxicity (kg 1.4-DB eq)	1.39	0.143
Marine Aquatic Ecotoxicity (kg 1.4-DB eq)	1.25 E3	220
Terrestrial Ecotoxicity (kg 1.4-DB eq)	0.105	0.00526
Photochemical Oxidation (kg C_2H_4 eq)	0.00104	0.000281

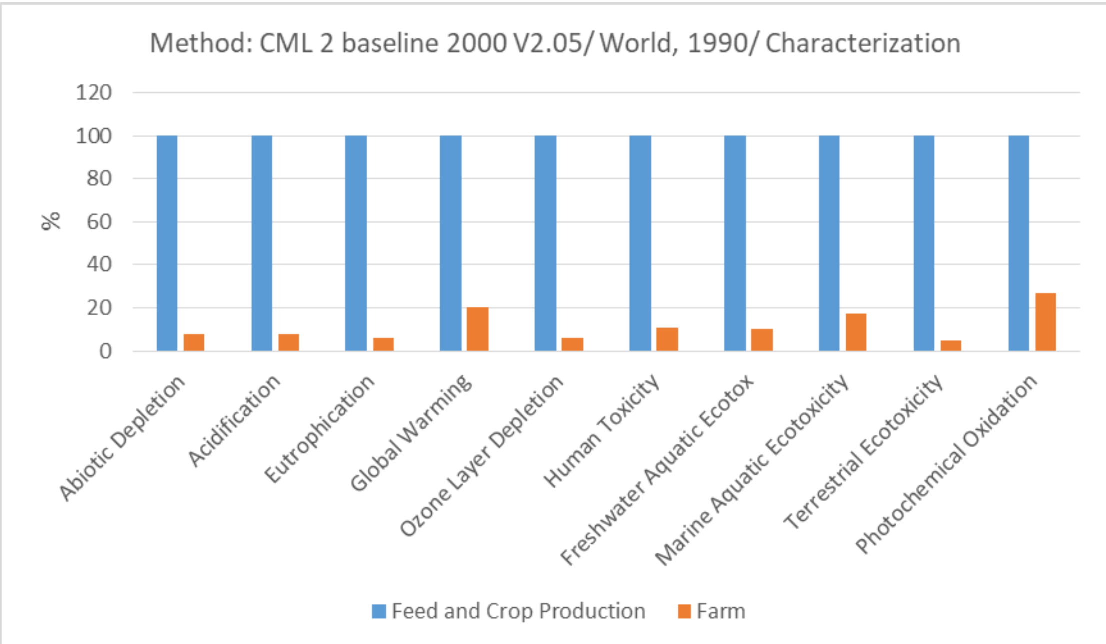

Figure 3: Comparison of Feed and Crop Production and Farm stages' contribution to impact categories.

According to figure 3, in cases of GWP, PhOP and MAETP the farm stage has a greater contribution in comparison with its share in the other impacts categories. It is important to know the contribution of processes implemented during the feed and crop production as well as farm stages to the most impactful impact categories.

4.1.1. Contribution of processes to GWP

The following figures offer a significant awareness regarding the contribution of procedures carried out for cultivation and farming purposes to the GWP. These processes can be the following: harvesting, transportation, combustion of light fuels or electricity production.

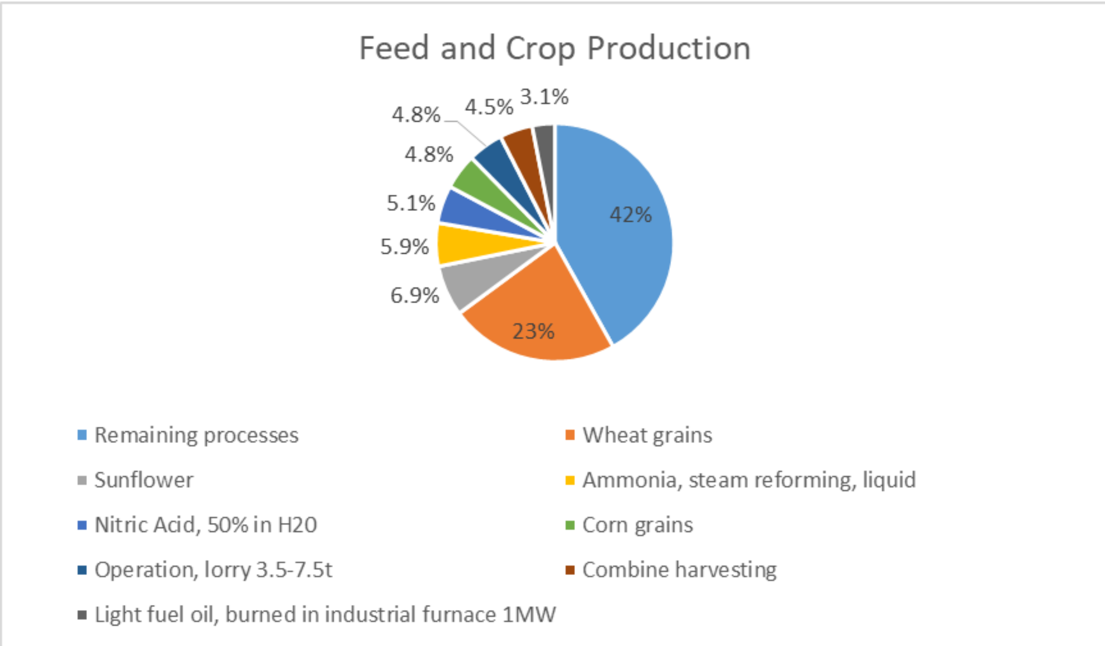

Figure 4: Contribution of processes take place in the Feed and Crop Production stage to Global Warming Potential, according to CML method.

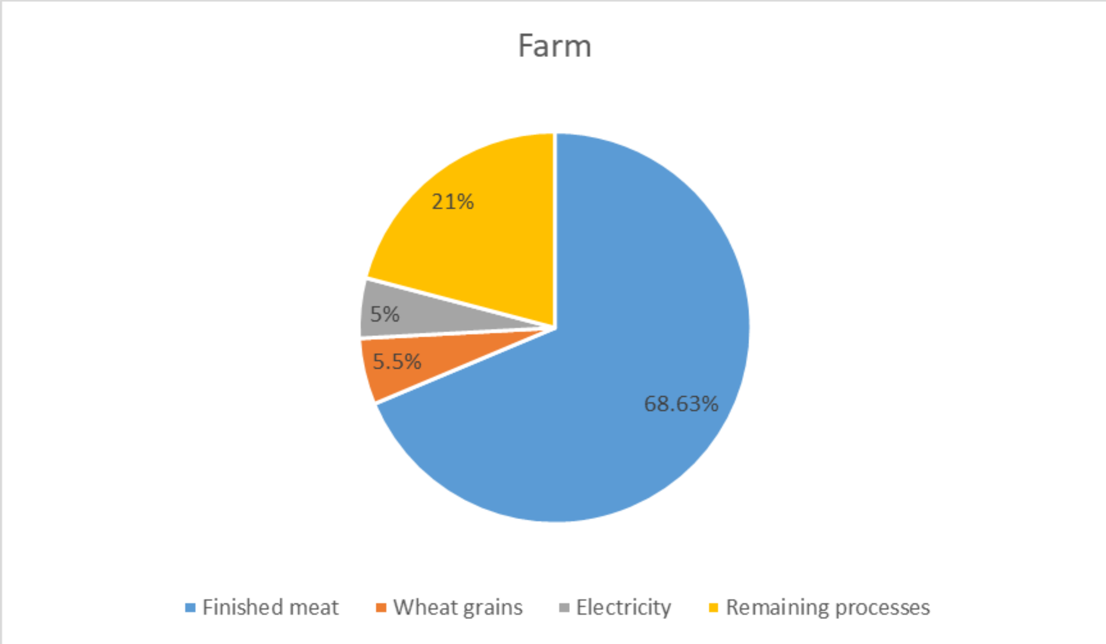

Figure 5: Contribution of processes take place in the Farm stage to Global Warming Potential, according to CML method.

According to figure 4, the combustion of light fuel oil in industrial furnace which was carried out during cultivation processes had the smallest contribution with a share of 1%. On the other hand, the cultivation of wheat grains reflected the 23% of total contribution. Also, remaining processes were responsible for the 42% of total value. In case of farm, the rearing of animals has as a result to affect the GWP through enteric fermentation and manure management. In this study, the dairy cattle breeding contributed to GWP with a share of 68.63%, while the electricity process affected the examined impact category representing the 5% of total contribution.

4.1.2. Contribution of processes to PhOP

The following figures represent the contribution of processes implemented in the feed and crop production as well as farm stages to the PhOP for a more detailed awareness concerning the causes which lead to environmental degradation.

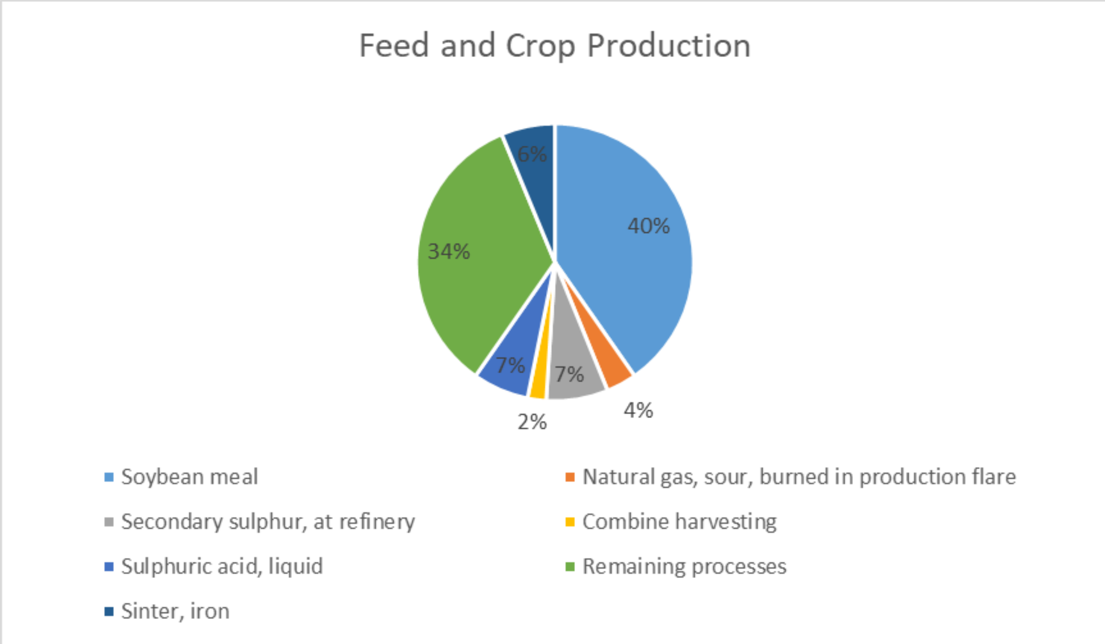

Figure 6: Contribution of processes take place in the Feed and Crop Production stage to Photochemical Oxidation Potential, according to CML method.

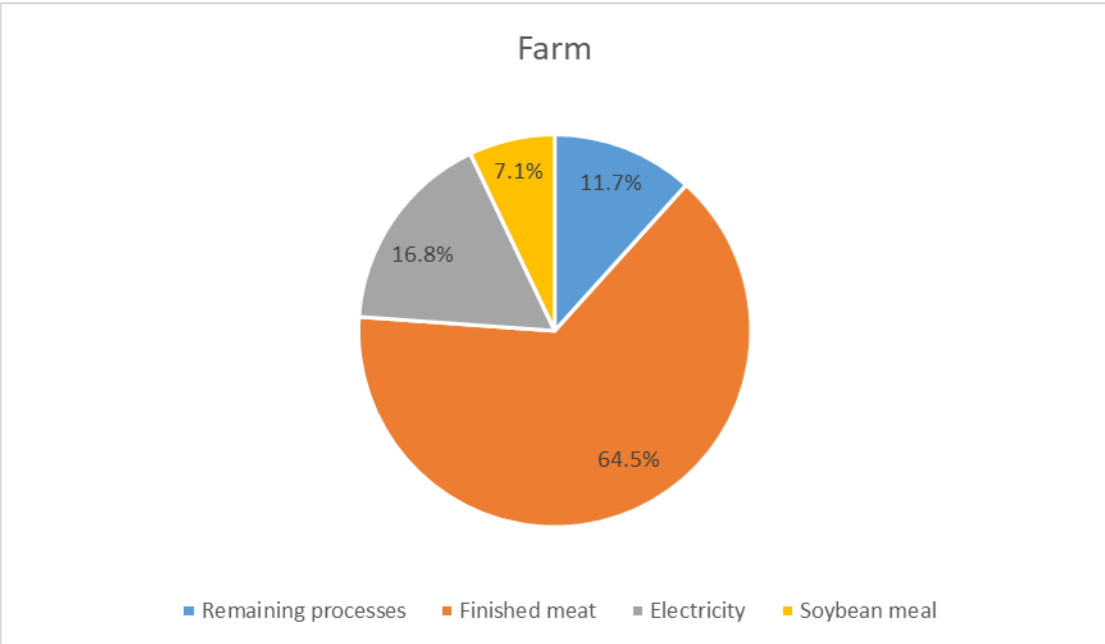

Figure 7: Contribution of processes take place in the Farm stage to Photochemical Oxidation Potential, according to CML method.

According to figure 6, the production of soybean meal represented the 40% of total contribution to PhOP. The remaining processes affected this impact category reflecting the 34% of total value. On the contrary, combine harvesting procedure represented only the 2% of total value. In case of farm phase, once again the breeding of meat strongly affected the PhOP with a share of 64.5%, while the consumption of soybean meal affected the impact category representing the 7.1% of total contribution.

4.1.3. Contribution of processes to MAETP

The following figures reflect the contribution of procedures implemented during the feed and crop production as well as farm stages to the MAETP. These figures help the stakeholders to be aware for the most impactful processes in the meat chain and find solutions to improve their environmental performance.

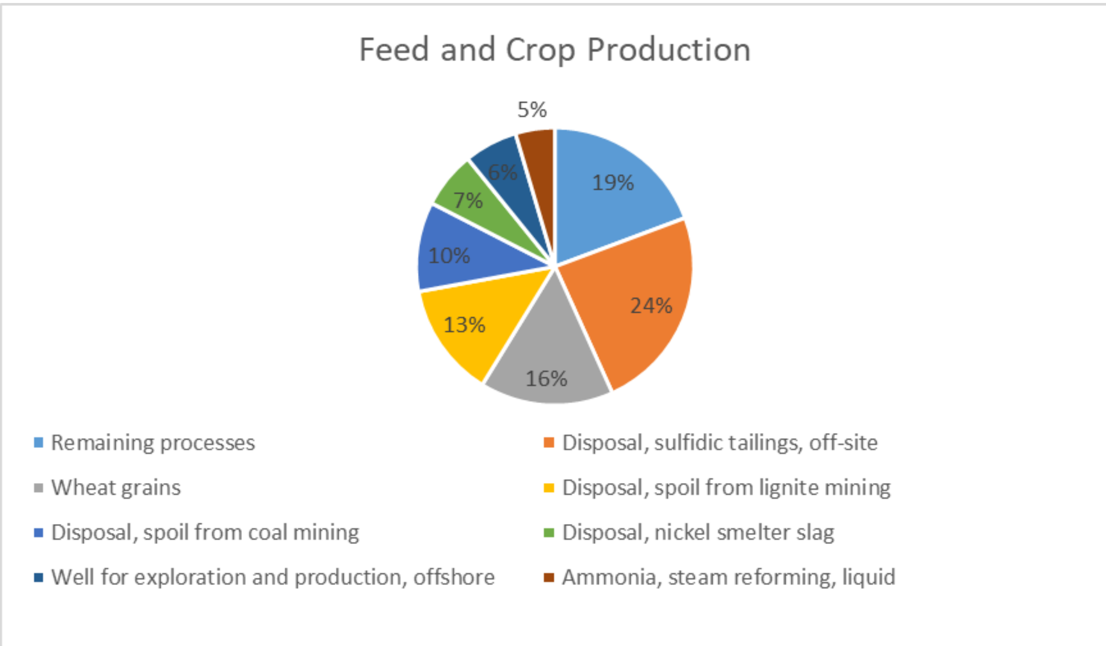

Figure 8: Contribution of processes take place in the Feed and Crop Production stage to Marine Aquatic Ecotoxicity according to CML method.

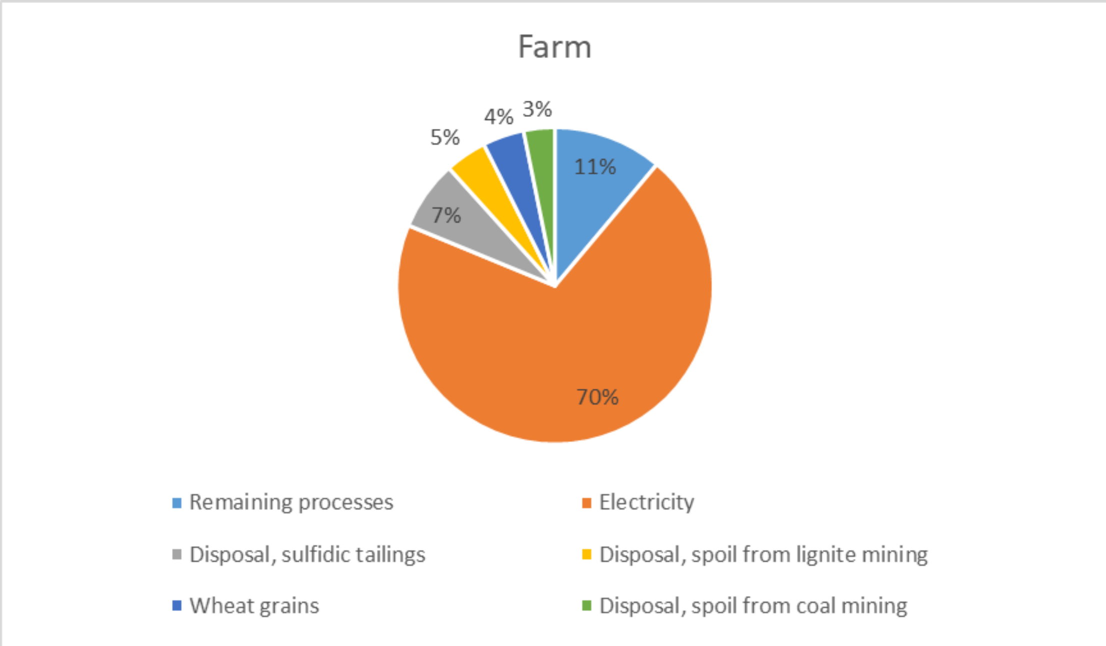

Figure 9: Contribution of processes take place in the Farm stage to Marine Aquatic Ecotoxicity according to CML method.

According to figure 8, the off-site disposal of sulfidic tailings affected the MAETP with a share of 24%. The remaining processes represented a contribution of 19% of total value. In case of farm stage, the electricity used for rearing purposes affected this impact category reflecting the 70% of total value. On the other hand, the disposal of spoil from coal mining as well as the disposal of coal from lignite mining to residential landfill had smaller contribution which was equal to 3% and 5% of total value, respectively.

4.2 2st Scenario's results

The implementation of the LCA methodology for the Scenario 2 – Alternative Scenario was carried out. As mentioned in the previous chapter, the Scenario 2 models the intensive system that take place in the dairy cattle farm under study with the valorisation of manure produced by animals. This means that this scenario encompasses improvement practices which get better the environmental performance of the farm. The results showed, once again that the feed and crop production stage had higher environmental impacts than the farming stage in all impact categories.

Nevertheless, both of stages affect the impact categories with significant smaller contribution.

More specifically, the utilization of digested manure as organic fertilizer to substitute N and P used for feed and crop production had as a result the reduction of substances such as sulphates, nitrates and phosphates produced through agricultural practices. Furthermore, the digested manure led to reduction of substances like CH_4 and N_2O (Reckmann et al., 2013). These, in turn led to lower impacts on affected categories such as AP, EP and GWP. Moreover, the anaerobic digestion of dairy cattle manure for biogas production (electricity, heat) led to avoided amounts of electricity imported from the national grid reducing the environmental impacts from the combustion of fossil fuels such as the emissions of GHGs which affect the GWP and ADP. It is worth mentioning that, not only the farm's needs for electricity can be fulfilled with the biogas production but its economic benefits can be increased without the cost for imported electricity from the national grid (Skunca et al., 2018). The reduction of environmental impacts related to improvement practices referred to scenario 2 are shown in table 9. Also, the comparison of feed and crop production as well as farm stages to impact categories are shown in the figure 10.

According to LCA results, in cases of AP and EP the feed and crop production had a strong contribution with a share of 97.4% and 95.7%, respectively, while the farm stage represented the 2.6% and 4.3% of total value, correspondingly. Regarding the ODP and PhOP, once again the feed and crop production stage had greater impact reflecting the 94.3% and 92.4% of total contribution, respectively, while the rearing of dairy cattle was responsible with a share of 5.7% and 7.6% of total contribution, correspondingly. The contribution of crop and feed production system in TEP was 95.5%, while the farm stage was responsible with a contribution of 4.5% of total value. In cases of FAETP and HTP the feed and crop production was the single activity responsible for contributing emissions. A significant achievement after the inclusion of the improvement practices concerns the GWP, ADP as well as MAETP. In these cases, the negative impact shown in table 11 as well as figure 10 indicates a positive effect on the environment.

Table 11: Values of impact categories, according to CML 2000 method

Impact Category	Feed and Crop Production	Farm
Abiotic Depletion (kg Sb eq)	0.0011	-0.000101
Acidification (kg SO_2 eq)	0.0314	0.000824
Eutrophication (kg PO_4 eq)	0.0545	0.00243
Global Warming (kg CO_2 eq)	-1.34	0.163
Ozone Layer Depletion (kg CFC-11 eq)	3.7 E-7	2.22 E-8
Human Toxicity (kg 1.4-DB eq)	0.894	0.0124
Fresh Water Aquatic Ecotoxicity (kg 1.4-DB eq)	1.39	0.00042
Marine Aquatic Ecotoxicity (kg 1.4-DB eq)	1.25 E3	-77.5
Terrestrial Ecotoxicity (kg 1.4-DB eq)	0.105	0.00494
Photochemical Oxidation (kg C_2H_4 eq)	0.000641	5.29 E-5

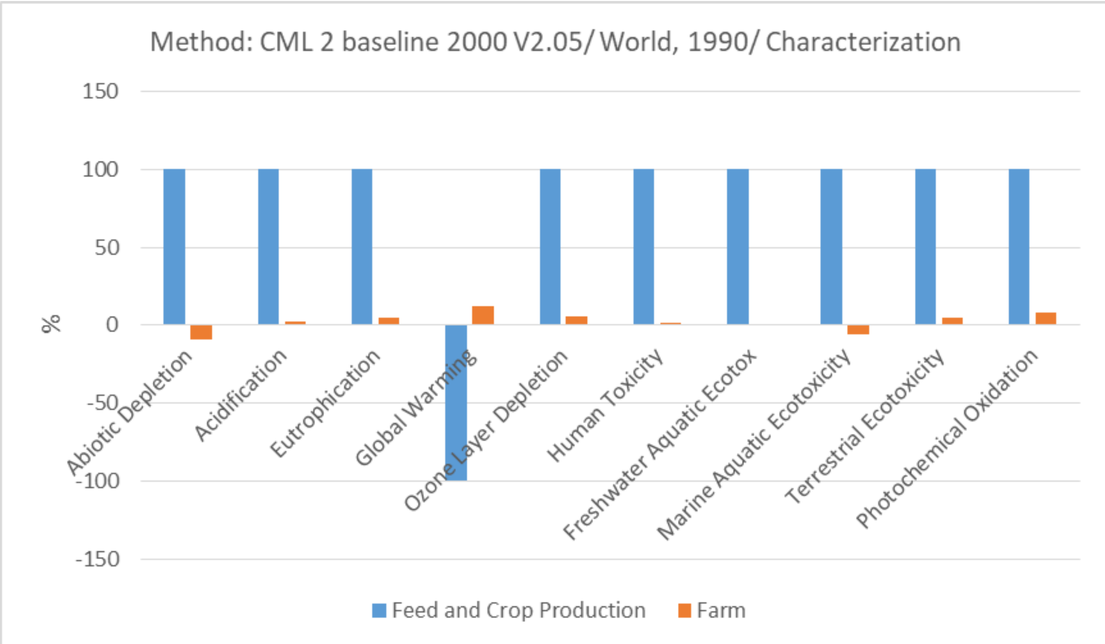

Figure 10: Comparison of Feed and Crop Production and Farm stages' contribution to impact categories.

4.3 Comparison of both Scenarios

The evaluation of the intensive system without valorisation of animal by-products and the intensive system with utilization of animal by-products was carried out through LCA approach. After the reporting of the LCA results in the above sections, a better understanding is achieved regarding the environment hotspots as well as the improvement of the environmental performance through mitigation processes.

More specifically, the scenario 1 had higher environmental impacts to all impact categories than scenario 2, with the feed and crop production stage to be the most impactful. In case of scenario 2, all impact categories had significant lower environmental impacts. Nevertheless, the feed and crop production stage continued to have the strongest contribution. Especially, concerning the GWP, ADP as well as MAETP the negative impact means a positive impact on the environment through the environmental benefits that occurred in the corresponding impact categories after the implementation of the mitigation processes. Detailed aggregation as well as comparison regarding the total contribution of both scenarios to all impact categories are shown in tables 12. The figure 11 is shown a comparison of both scenarios' total contribution to all impact categories assessed.

Table 12: Values of impact categories for both scenarios, according to CML 2000 method

	Scenario 1			Scenario 2			
Impact Category	Feed and Crop Production	Farm	TC_1*	Feed and Crop Production	Farm	TC_2*	Comparison of TC for both scenarios
Abiotic Depletion (kg Sb eq)	0.0193	0.00151	0.02081	0.0011	-0.000101	0.000999	$TC_2<TC_1$
Acidification (kg SO_2 eq)	0.0514	0.00413	0.05553	0.0314	0.000824	0.032224	$TC_2<TC_1$
Eutrophication (kg PO_4 eq)	0.0577	0.00344	0.06114	0.0545	0.00243	0.05693	$TC_2<TC_1$
Global Warming (Kg CO_2 eq)	5.09	1.02	6.11	-1.34	0.163	-1.177	$TC_2<TC_1$
Ozone Layer Depletion (kg CFC-11 eq)	3.7 E-7	2.18 E-8	3.918 E-7	3.7 E-7	2.22 E-8	3.922 E-7	$TC_2<TC_1$
Human Toxicity (kg 1.4-DB eq)	0.919	0.0975	1.0165	0.894	0.0124	0.9064	$TC_2<TC_1$
Fresh Water Aquatic Ecotoxicity (kg 1.4-DB eq)	1.39	0.143	1.533	1.39	0.00042	1.39042	$TC_2<TC_1$
Marine Aquatic Ecotox (kg 1.4-DB eq)	1.25 E3	220	1.47 E3	1.25 E3	-77.5	1.1725 E3	$TC_2<TC_1$
Terrestrial Ecotoxicity (kg 1.4-DB eq)	0.105	0.00526	0.11026	0.105	0.00494	0.10994	$TC_2<TC_1$
Photochemical Oxidation (kg C_2H_4 eq)	0.00104	0.000281	0.001321	0.000641	5.29 E-5	6.939 E-4	$TC_2<TC_1$

TC_1*: Total Contribution for scenario 1
TC_2*: Total Contribution for scenario 2

According to table 12, the total contribution of scenario 2 to all impact categories is lower than scenario 1. Therefore, scenario 2 has a better environmental performance being a more environmentally friendly scenario.

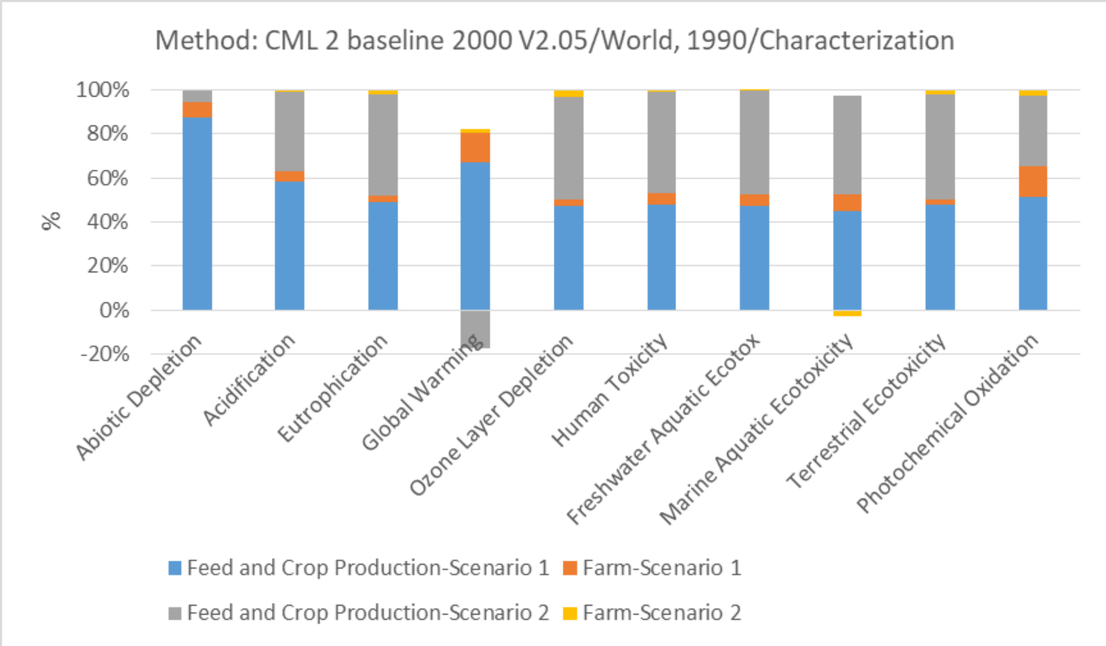

Figure 11: Comparison of both scenarios' contribution to impact categories.

Therefore, the awareness of a company's environmental performance and the detection of the weak and key points for impact mitigation is crucial. Then, the selection of the most improved actions can offer significant environmental advantages leading to a more sustainable society.

4.4 Improvement Actions for meat companies

The key stakeholders in the meat production chain it is important to be aware of their environmental footprint and adopt improvement practices in order to become more sustainable. Financial resources and the willingness of meat companies to undertake improvement actions are the key factors which determine the implementation of these actions in farms, slaughterhouses, processing plants, retail stores and households (Skunca et al., 2018). These possible improvements processes are described in the following paragraphs.

First of all, the production of feed ingredients especially soybean meal has significant contribution to environmental impact categories having as a result the feed and crop production to be the most impactful stage. For this reason special attention have to be given in this phase (Gonzalez et al., 2014). One solution could be the replacement of soybean-based ingredients with other feeds the cultivation of them do not affect the environment. According to Baumgartner et al. (2008) grain legumes can be used as protein source in feed reducing the environmental impacts, due to their cultivation does not require mineral fertilizer application. Moreover, the usage of feeds produced locally lead to reduction of input rates for crop production and processing, enhancing the environmental performance (Baumgartner et al., 2008).

Secondly, another improvement action is the utilization of the animal by-products from farms or slaughterhouses (slurry, and residues like stomach and intestines) to go through anaerobic digestion or incineration in order to recover energy (Skunca et al., 2018; Gonzalez-Garcia 2015). Specifically, according to Mainali et al. (2017) the valorisation of chicken litter through anaerobic digestion has as a result the production of biogas used for electricity generation, reducing the emissions of GHGs by 76%. Furthermore, the replacement of liquid petroleum gas with biogas for cooking purposes lead to 65% reduction of GHGs (Mainali et al., 2017). Not only the reduction of fuel and electricity contribute to the decrease of severe environmental impacts but increase the economic benefits as well (Skunca et al., 2018). In this case study the anaerobic digestion of animal manure was proposed to further reduce the environmental impacts by energy recovery and a reduction until 90% of CH_4 emissions as well as more than 50% of N_2O emissions (Reckmann et al., 2013).

Thirdly, the manure handling and storage is responsible for NH_3 emissions which strongly affect the AP and EP impact categories. One solution could be the use of heat exchangers in farms for ventilation purposes. Thus, the reduction of NH_3 emissions is succeed and healthy conditions for the animals are achieved (Katajajuuri, 2007). The application of manure on agricultural land as organic fertilizer decreases the environmental impacts, due to the replacement of mineral fertilizers took place by this way. Especially, as proposed in this case study after the bio-digestion of manure the substitution rates can be increased from 75% to 80% (Reckmann et al., 2013).

In addition to the above, the utilization of energy efficient systems in farms, slaughterhouses and meat processing plants can lead to energy savings. Moreover, the usage of energy efficient refrigerators, freezers and stoves in households not only decrease the environmental footprint of the consumers but reduce their costs by lowering their energy bills. Last but not least, another mitigation process is the recycling of household waste which contribute to a more sustainable consumption (Skunca et al., 2018).

5. Conclusions

Livestock sector activities have strong contribution to all impact categories all over the world. Except from the various emissions into the environment, the environmental impacts arise from the consumption of resources related to production processes in meat chain. Especially, meat has the greatest environmental impact compared to other food products, because of the inefficiency of animals in converting feed to meat (Djekic, 2015). Life Cycle Assessment (LCA) is a scientific methodology for assessing and comparing the environmental impacts of livestock production systems during their life cycle (Tsutsumi et al., 2018).

The stakeholders in meat consumption chain have to be aware of their environmental performance. The implementation of LCA approach can offer a comprehensive overview regarding the environmental impacts occurred by meat production as well as the weak and key points for impact mitigation. There are many LCA studies which have evaluated the environmental impacts of meat products during their life cycle (McAuliffe et al., 2016).

In this study, the implementation of LCA methodology to evaluate two different scenarios was carried out. The first scenario modeled the intensive production system that take place in the farm under study without the valorisation of animal's by-products. The second scenario modeled the current situation in the dairy cattle farm with the valorisation of animal by-products. This valorisation concerns the anaerobic digestion of the dairy cattle manure for biogas production (electricity, heat) as well as the utilization of the digested manure as organic fertilizer to substitute N and P used for feed and crop production.

The LCA results shown that the feed and crop production stage had the strongest contribution to all impact categories in both scenarios. In case of farm stage the enteric fermentation as well as the manure management was responsible for the contribution to impact categories such as GWP and PhOP. Moreover, the LCA results demonstrated significant reduction to all impact categories in case of scenario 2 which encompassed the utilization of the dairy cattle manure. Especially, in cases of GWP, ADP as well as MAETP a positive effect on the environment were been accomplished. Therefore, the awareness of a company's environmental performance and the adoption of improved actions can offer significant environmental benefits.

The key stakeholders in the meat production chain have to seek the most efficient practices for impact mitigation after the detection of the weak and key points through the application of LCA method. One solution could be the replacement of soybean-based ingredients with grain legumes the cultivation of them does not require mineral fertilizer application (Baumgartner et al., 2008). Moreover, an efficient action is the utilization of the animal by-products from farms or slaughterhouses (slurry, and residues like stomach and intestines) to produce biogas (electricity, heat) (Gonzalez-Garcia et al., 2015). In addition, another effective practice is the application of animal manure on agricultural land as organic fertilizer to replace the mineral fertilizers (Reckmann et al., 2013). Furthermore, the usage of energy efficient systems such as refrigerators and freezers decreases the environmental footprint as well as the energy bills (Skunca et al., 2018).

To conclude, it is worth mentioning that all meat companies must be conform to European regulation, strategies and policies in order to be environmentally friendly and improve its contribution to sustainable development. Moreover, the willingness of stakeholders to undertake effective actions as well as the financial resources are the key factors which determine the implementation of mitigation processes.

Bibliography

1. Allievi, F., Vinnari, M., & Luukkanen, J. (2015). Meat consumption and production-Analysis of efficiency, sufficiency and consistency of global trends. Journal of Cleaner Production 92: 142-151

2. Bartzanas T., Anestis V., Papaioannou Ch., Kittas C. (2015). Assessment of environmental footprint of livestock facilities. International Conference on Food and Biosystems Engineering, 28-31 May 2015, Mykonos island.

3. Basset-Mens, C., Van der Werf, H.M.G., (2005). Scenario-based environmental assessment of farming systems: the case of pig production in France. Agriculture, Ecosystems and Environment 105: 127–144.

4. Baumgartner, D.U., De Baan, L., Nemecek, T., 2008. European Grain Legumes - Environment-friendly Animal Feed: Life Cycle Assessment of Pork, Chicken Meat, Egg and Milk Production. Grain Legumes Integrated Project Report. Agroscope Reckenholz-Tanikon Research Station ART, Zürich.

5. Bava L., Zucali M., Sandrucci A. , Tamburini A. (2017). Environmental impact of the typical heavy pig production in Italy. Journal of Cleaner Production 140: 685-691.

6. Biagini D., Lazzaroni C. (2018). Eutrophication risk arising from intensive dairy cattle rearing systems and assessment of the potential effect of mitigation strategies. Agriculture, Ecosystems & Environment 266: 76-83

7. Biswas D.K., Naude G. (2016). A life cycle assessment of processed meat products supplied to Barrow Island: A Western Australian case study. Journal of Food Engineering 180: 48-59.

8. Cesari V., Zucali M., Sandrucci A., Tamburini A., Bava L., Toschi I. (2017). Environmental impact assessment of an Italian vertically integrated broiler system through a Life Cycle approach. Journal of Cleaner Production 143: 904-911.

9. Coulomb, D. (2008). Refrigeration and cold chain serving the global food industry and creating a better future: Two key IIR challenges for improved health and environment. Trends in Food Science & Technology 19: 413-417

10. Da Luz L. M., De Francisco A.C., Moro Piekarski C., Salvador R. (2018). Integrating life cycle assessment in the product development process: A methodological approach. Journal of Cleaner Production 193 (2018) 28-42

11. Da Silva V.P., Cherubini E., Soares S.R. (2012). Comparison of two production scenarios of chickens consumed in France. 8th International Conference on LCA in the Agri-Food Sector, Rennes, France.

12. De Vries M., Van Middelaar C.E., De Boer I.J.M. (2015). Comparing environmental impacts of beef production systems: A review of life cycle assessments. Livestock Science 178: 279–288

13. Dick M., Da Silva M.A, Dewes H (2015). Life cycle assessment of beef cattle production in two typical grassland systems of southern Brazil. Journal of Cleaner Production 96: 426-434

14. Djekic I., Tomasevic I. (2016). Environmental impacts of the meat chain - Current status and future perspectives. Trends in Food Science & Technology 54: 94-102

15. Djekic I. (2015). Environmental impact of meat industry – current status and future perspectives. Procedia Food Science 5: 61-64

16. De Vries M., De Boer I.J.M. (2010). Comparing environmental impacts for livestock products: A review of life cycle assessments. Livestock Science 128: 1–11

17. De Vries M., Van Middelaar C.E., De Boer I.J.M. (2015). Comparing environmental impacts of beef production systems: A review of life cycle assessment. Livestock Science178: 279–288.

18. E-nomothesia.gr. Law 374/2001. Available at: https://www.e-nomothesia.gr/kat-agrotike-anaptukse/ktenotrophia/pd-374-2001.html, accessed December 2018.

19. E-nomothesia.gr. Law 4056/2012. Available at: https://www.e-nomothesia.gr/kat-agrotike-anaptukse/ktenotrophia/n-4056-2012.html, accessed December 2018.

20. E-nomothesia.gr. Law 79/2007. Available at: https://www.e-nomothesia.gr/kat-sfageia/pd-79-2007.html, accessed December 2018.

21. European Commission. Council Directive 98/58/EC of 20 July 1998 concerning the protection of animals kept for farming purposes. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31998L0058 , accessed December 2018.

22. European Commission. Council Regulation (EC) No 1/2005 of 22 December 2004 on the protection of animals during transport and related operations and amending Directives 64/432/EEC and 93/119/EC and Regulation (EC) No 1255/97. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32005R0001, accessed December 2018.

23. European Commission. Council Regulation (EC) No 1099/2009 of 24 September 2009 on the protection of animals at the time of killing. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32009R1099, accessed December 2018.

24. European Commission. Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labeling of organic products and repealing Regulation (EEC) No

2092/91. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32007R0834, accessed December 2018.

25. Gonzalez-García S., Belo S., Dias A.C., Rodrigues J.V., Da Costa R.R., Ferreira A, De Andrade L.P., Arroja L. (2015). Life cycle assessment of pigmeat production: Portuguese case study and proposal of improvement options. Journal of Cleaner Production 100: 126-139

26. González-García S., Gomez-Fernández Z, Dias A.C., Feijoo G., Moreira T, Arroja L. (2014). Life Cycle Assessment of broiler chicken production: a Portuguese case study. Journal of Cleaner Production 74: 125-134.

27. Giannenas I., Bonos E., Anestis V., Filioussis G., Papanastasiou D.K., Bartzanas T., Papaioannou N., Tzora A., Skoufos I. (2017). Effects of Protease Addition and Replacement of Soybean Meal by Corn Gluten Meal on the Growth of Broilers and on the Environmental Performances of a Broiler Production System in Greece. PLoS ONE 12(1): e0169511

28. Guerrero-Baena M.D., Gomez-Limon J.A., Fruet J.V. (2015). A multicriteria method for environmental management system selection: an intellectual capital approach. J. Clean. Prod. 105: 428-437

29. Herrmann I. T., Moltesen A. (2015). Does it matter which Life Cycle Assessment (LCA) tool you choose? – a comparative assessment of SimaPro and GaBi. Journal of Cleaner Production 86: 163-169

30. Huerta A.R., Güereca L.P., De la Salud Rubio Lozano M (2016). Environmental impact of beef production in Mexico through life cycle assessment. Resources, Conservation and Recycling 109, 44-53

31. ISO, 2006a. ISO 14040 Standard. In: Standardization, I.O.f. (Ed.), Environmental Management - Life Cycle Assessment - Principles and Framework ed, Geneva, Switzerland.

32. ISO, 2006b. ISO 14044 Standard. In: Standardization, I.O.f. (Ed.), Environmental Management - Life Cycle Assessment - Requirements and Guidelines ed, Geneva, Switzerland.

33. IPCC, 2006. Greenhouse Gas Inventories. In: 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 4, Agriculture, Forestry, and other Land Use, Chapter 1

34. Kalhor, T., Rajabipour, A., Akram, A., Sharifi, M., 2016. Environmental impact assessment of chicken meat production using life cycle assessment. Information Processing in Agriculture 3 (4): 262-271.

35. Katajajuuri, J.M., 2008. Experiences and improvement possiblities — LCA case study of broiler chicken production. Proceedings of the 6th International Conference on Life Cycle Assessment in the Agri-Food Sector. Novermber 12–14, Zurich, Switzerland.

36. Lacasa, E., Santolaya, J.L., Biedermann, A., 2016. Obtaining sustainable production from the product design analysis. J. Clean. Prod. 139 (Suppl. C), 706-716.

37. Lopez-Andres J.J.., Aguilar-Lasserre A.A., Morales-Mendoza L.F., Azzaro-Pantel C., Perez-Gallardo J.R., Rico-Contreras J.O (2018). Environmental impact assessment of chicken meat production via an integrated methodology based on LCA, simulation and genetic algorithms. Journal of Cleaner Production 174: 477-491

38. Lukewille A. & Alewell C. (2008). Acidification. Reference Module in Earth Systems and Environmental Sciences. Encyclopedia of Ecology (Second Edition) 2: 233-241

39. Lundie, S., Ciroth, A., Huppes, G., 2007. Inventory Methods in LCA: Towards Consistency and Improvement, Life Cycle Inventory (LCI) Programme. UNEPSETAC Life Cycle Initiative

40. Magdelaine, P., Spiess, M.P., Valceschini, E., 2008. Poultry meat consumption trendsin Europe. World's Poult. Sci. J. 64, 53e64.

41. Mainali, B., Emran, S.B., Silveira, S., 2017. Greenhouse gas mitigation using poultry litter management techniques in Bangladesh. Energy 127, 155-166.

42. McAuliffe G.A., Chapman D.V., Sage C.L. (2016). A thematic review of life cycle assessment (LCA) applied to pig production. Environmental Impact Assessment Review 56: 12–22

43. Morales-Mendez J., Silva-Rodriguez R. (2018). Environmental Assessment of ozone layer depletion due to the manufacture of plastic bags. Heliyon 4(12):e01020

44. Moreno, A., Cappellaro, F., Masoni, P., Amato, A., 2011. Application of product data technology standards to LCA data. J. Ind. Ecol. 15 (4), 483-495.

45. Murillo-Luna J.L., Garces-Ayerbe C., Rivera-Torres P. (2011). Barriers to the adoption of proactive environmental strategies. J. Clean. Prod. 19: 1417-1425.

46. Nguyen, T.L.T., Hermansen, J.E., Mogensen, L., 2011. Environmental Assessment of Danish Pork. Aarhus University, Aarhus, Denmark.

47. Nguyen T.L.T, Hermansen J.E., Mogensen L (2010). Environmental consequences of different beef production systems in the EU. Journal of Cleaner Production 18: 756–766.

48. Noya I., Aldea X., González-García S, Gasol C.M., Moreira M.T., Amores M.J., Marín D., Boschmonart-Rives J. (2017). Environmental assessment of the entire pork value chain in Catalonia – A strategy to work towards Circular Economy. Science of the Total Environment 589:122–129.

49. Ogino A., Orito H., Shimada K., Hirooka H. (2007). Evaluating environmental impacts of the Japanese beef cow–calf system by the life cycle assessment method. Animal Science Journa*l* 78: 424–432.

50. Perez-Martinez M.M., Noguerol R., Casales B.I., Lois R., Soto B. (2018). Evaluation of environmental impact of two ready-to-eat canned meat products using Life Cycle Assessment. Journal of Food Engineering 237: 118–127.

51. Reckmann K., Traulsen I., Krieter J. (2013). Life Cycle Assessment of pork production: A data inventory for the case of Germany. Livestock Science 157: 586–596.

52. Reckmann K., Traulsen I., Krieter J. (2012). Environmental Impact Assessment-methodology with special emphasis on European pork production. Journal of Environmental Management 107: 102-109

53. Roy P., Orikasa T., Thammawong M., Nakamura N., Xu Q., Shiina T. (2012). Life cycle of meats: An opportunity to abate the greenhouse gas emission from meat industry in Japan. Journal of Environmental Management 93: 218-224.

54. SimaPro. (2018), *SimaPro LCA Software*, accessed December 2018, Available at: https://simapro.com/about/

55. SimaPro, (PRé, various authors) (2016). *SimaPro Database Manual - Methods Library*. [ebook] Available at: https://www.pre-sustainability.com/download/DatabaseManualMethods.pdf [Accessed Jan. 2019].

56. Skunca D., Tomasevic I, Djekic I. (2015). Environmental performance of the poultry meat chain – LCA approach. Procedia Food Science 5: 258 – 261

57. Skunca D., Tomasevic I, Nastasijevic I, Tomovic V., Djekic I (2018). Life cycle assessment of the chicken meat chain. Journal of Cleaner Production 184: 440-450.

58. Steinfeld H., Gerber P., Wassenaar T., Castel V., Rosales M., De Haan C., (2006). Livestock's long shadow: environmental issues and options. FAO, Rome, Italy 978-92-5-105571-7.

59. Telenko, C., O'Rourke, J.M., Seepersad, C.C., Webber, M.E., 2016. A compilation of design for environment guidelines. J. Mech. Des. 138 (3).

60. Tichenor N.E., Peters C.J., Norris G.A., Thoma G, Griffin T.S (2017). Life cycle environmental consequences of grass-fed and dairy beef production systems in the Northeastern United States. Journal of Cleaner Production 142: 1619-1628

61. Tiruta-Barna, L., Benetto, E., Perrodin, Y., 2007. Environmental impact and risk assessment of mineral wastes reuse strategies: review and critical analysis of approaches and applications. Resources, Conservation and Recycling 50: 351-379

62. Tsutsumi M., Ono Y, Ogasawara H, Hojito M (2018). Life-cycle impact assessment of organic and non-organic grass-fed beef production in Japan. Journal of Cleaner Production 172: 2513-2520

63. Wang H., Xu J., Sheng L, Liu X. (2018). Effect of addition of biogas slurry for anaerobic fermentation of deer manure on biogas production. Energy 165 (2018): 411-418

64. Weidema, B.O., Thrane, M., Christensen, P., Schmidt, J., Løkke, S., 2008a. Carbon footprint. Journal of Industrial Ecology 12: 3-6

65. Williams, A.G., Audsley, E., Sandars, D.L., 2006. Determining the Environmental Burdens and Resource Use in the Production of Agricultural and Horticultural Commodities. Cranfield University and Defra. Main Report, Defra Research Project

6. Appendix I

In the following networks the arrows present the flows between the processes. The red bar charts indicate the environmental load generated in each process and its upstream processes. The green lines and bars indicate a negative impact which means positive effect on the environment.

Scenario 1 (Feed and Crop Production): Network chart flows (NCF), which refers to impact categories resulted from CML 2001 method

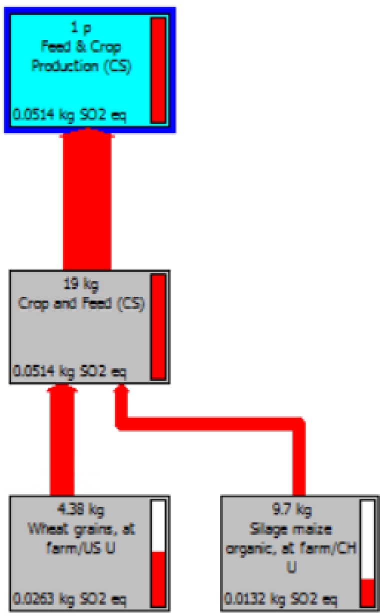

Figure I.1: NCF referred to AP

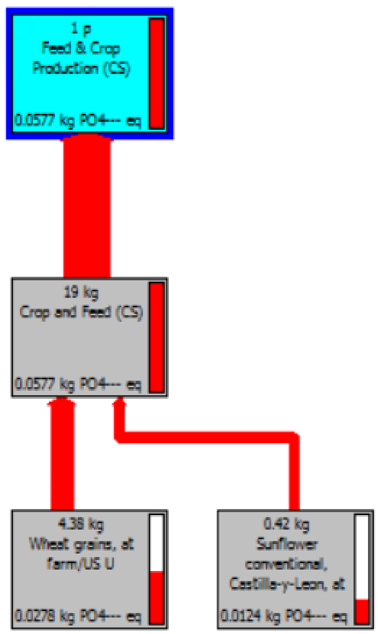

Figure I.2: NCF referred to EP

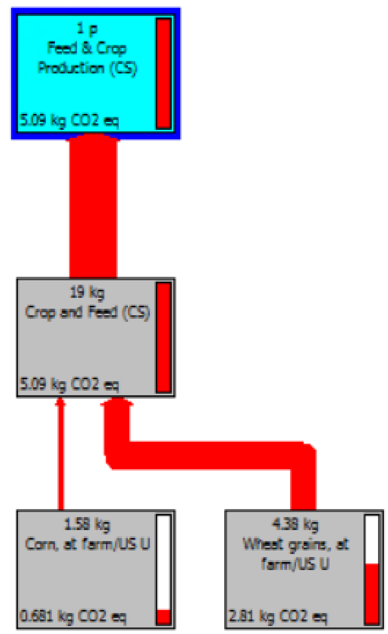

Figure I.3: NCF referred to GWP

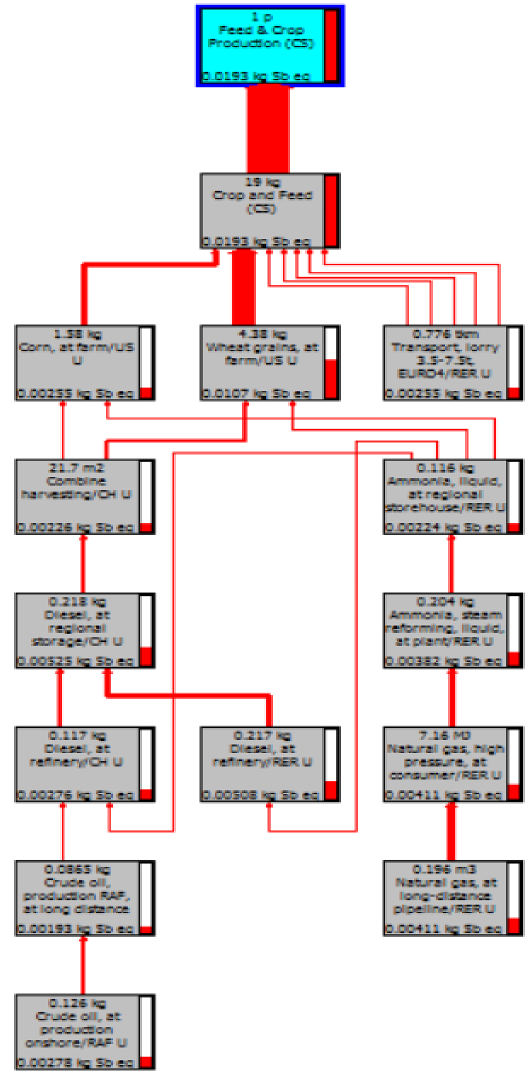

Figure I.4: NCF referred to ADP

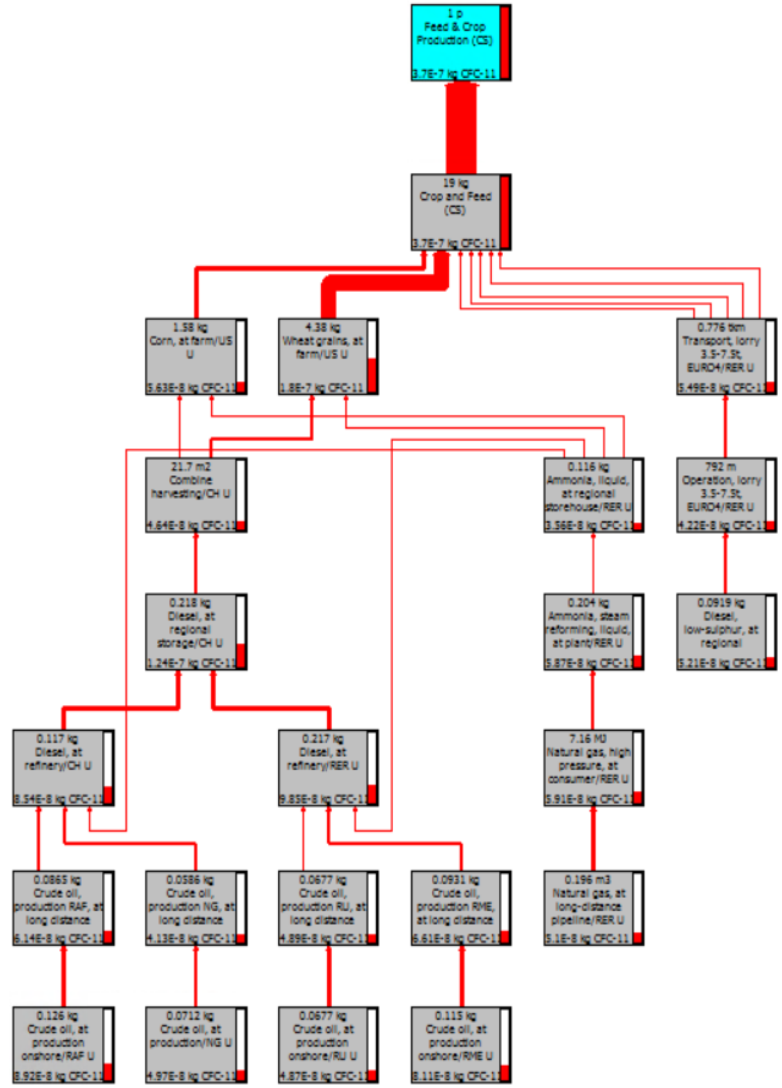

Figure I.5: NCF referred to ODP

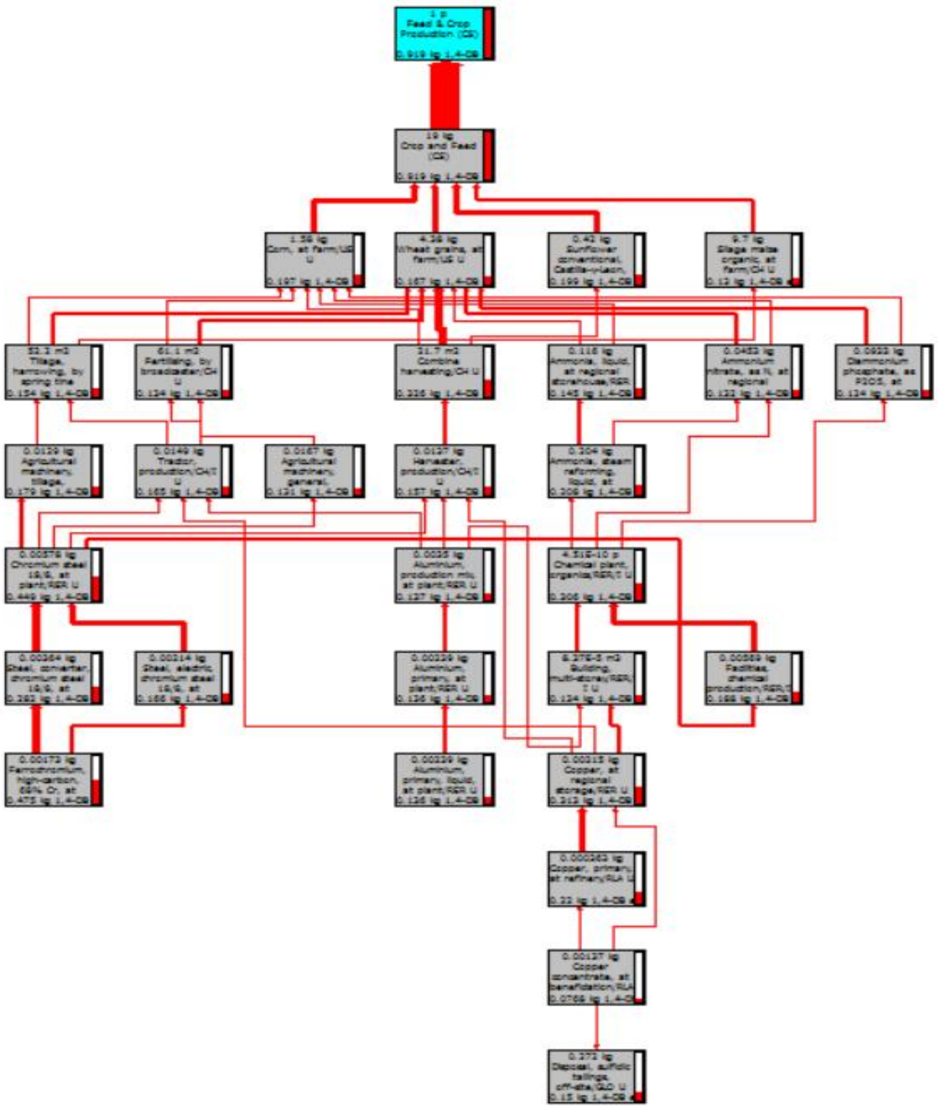

Figure I.6: NCF referred to HTP

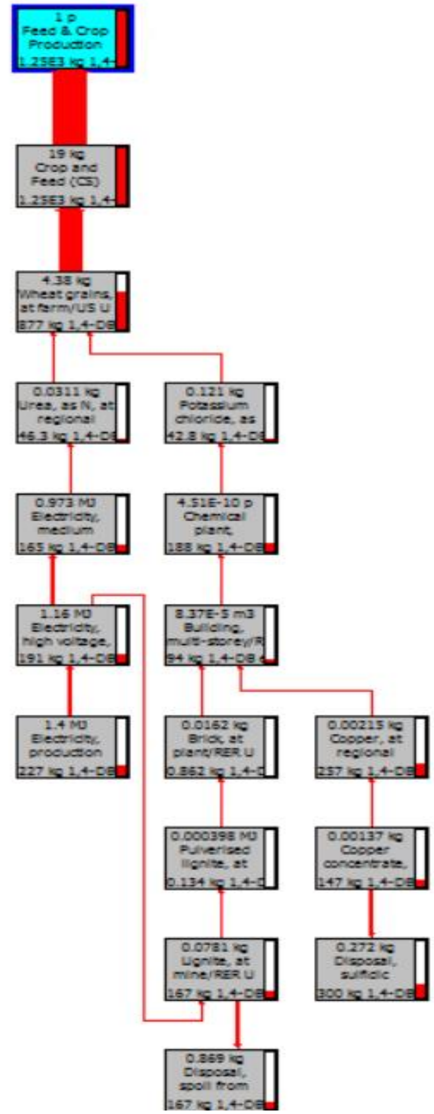

Figure I.7: NCF referred to MAETP

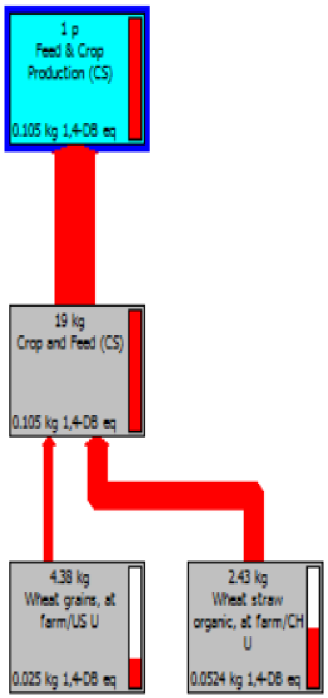

Figure I.8: NCF referred TEP

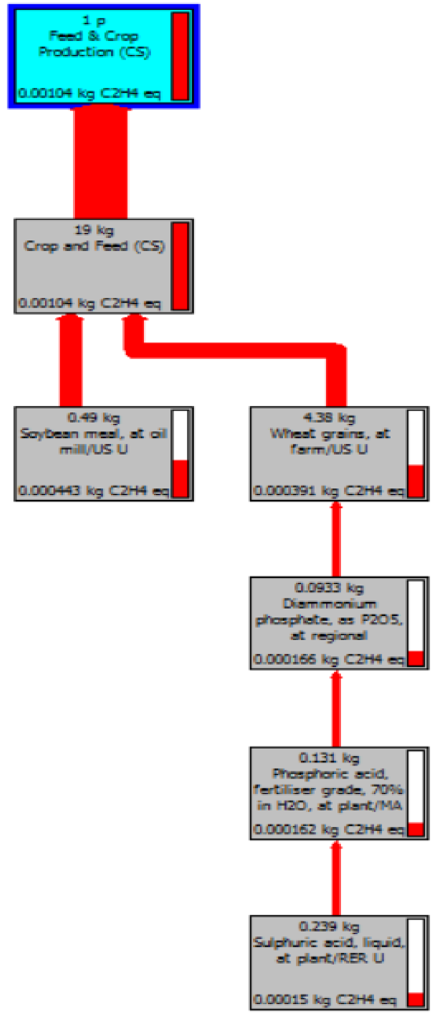

Figure I.9: NCF referred to PhOP

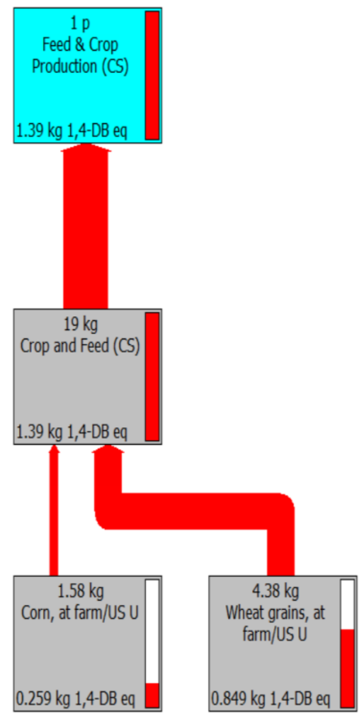

Figure I.10: NCF referred to FAETP

Scenario 1 (Farm): Network chart flows (NCF), which refers to impact categories resulted from CML 2001 method

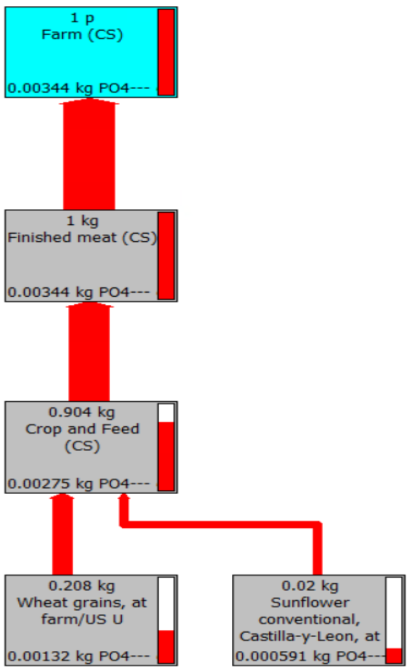

Figure I.11: NCF referred to EP

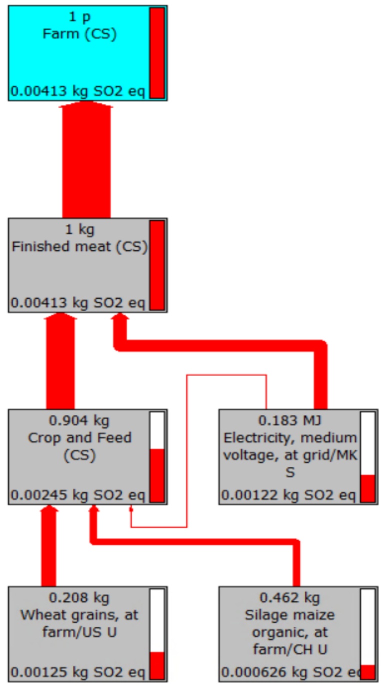

Figure I.12: NFC referred to AP

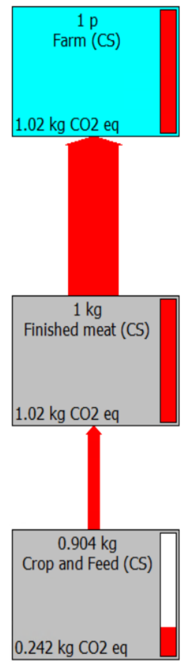

Figure I.13: NFC referred to GWP

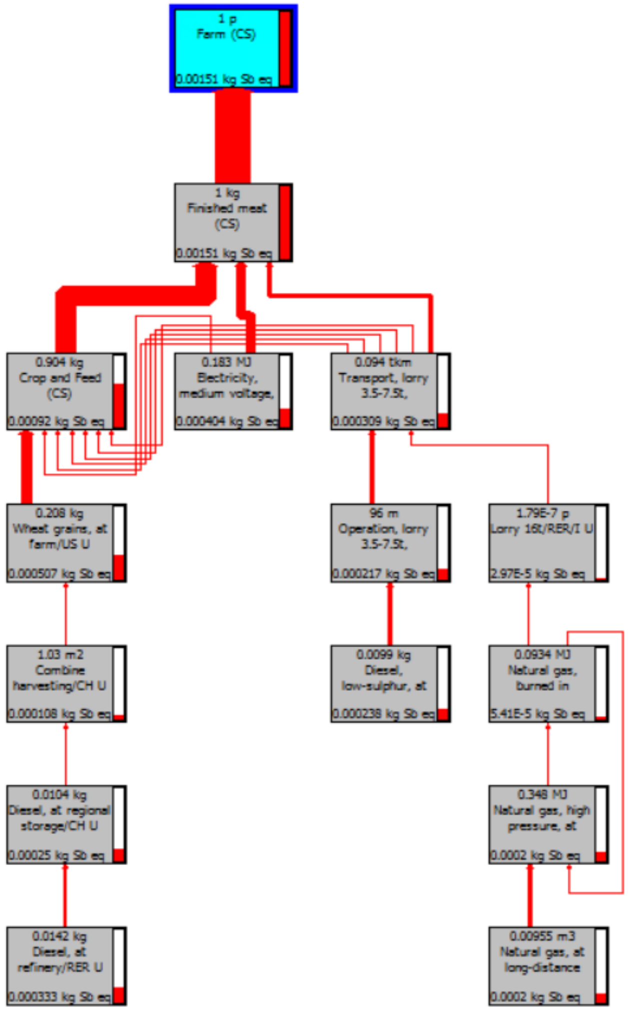

Figure I.14: NCF referred to ADP

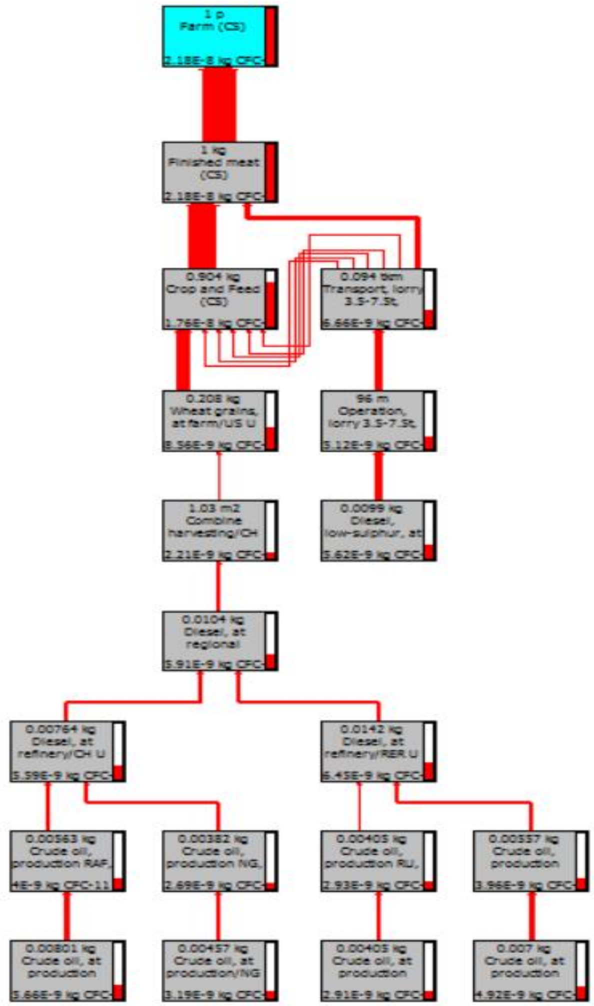

Figure I.15: NFC referred to ODP

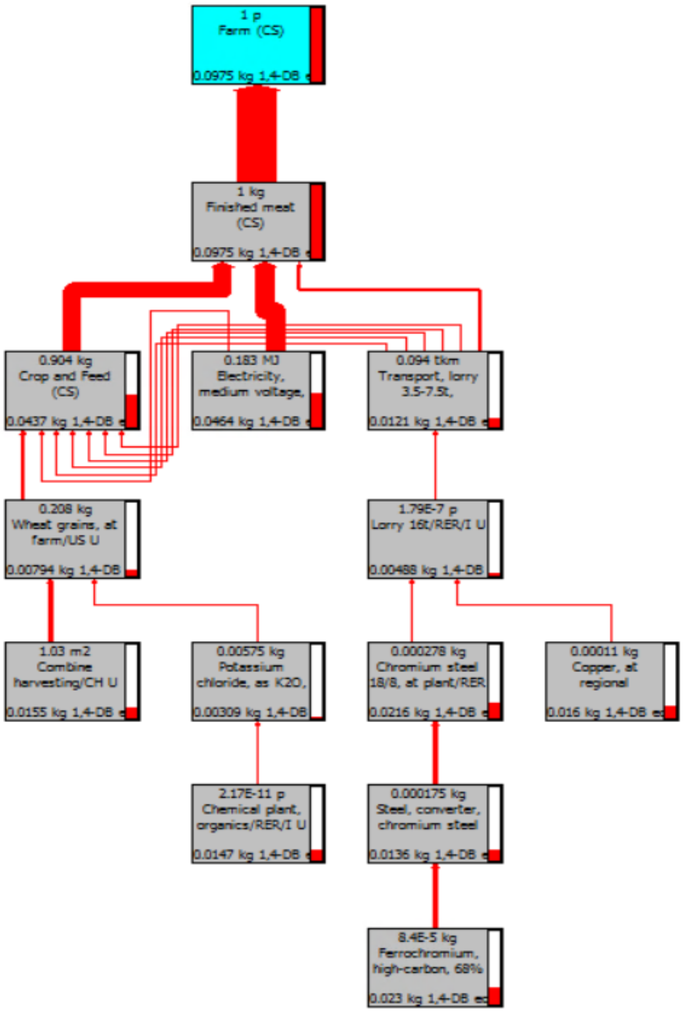

Figure I.16: NFC referred to HTP

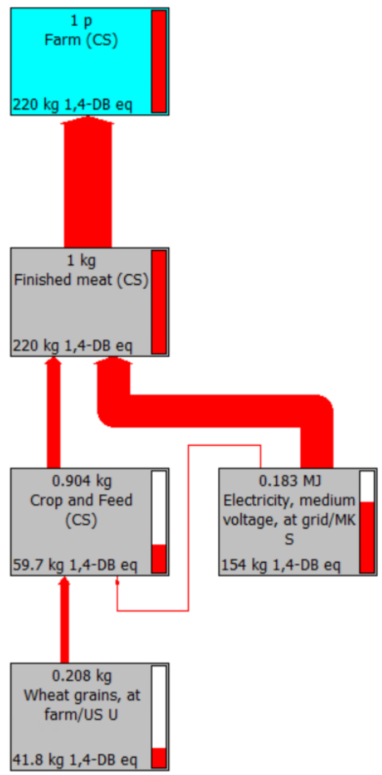

Figure I.17: NFC referred to MAETP

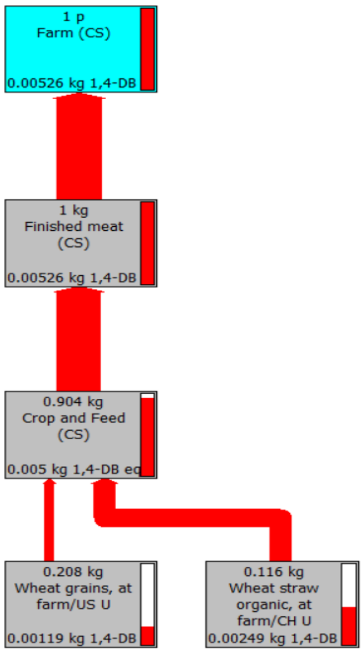

Figure I.18: NFC referred to TEP

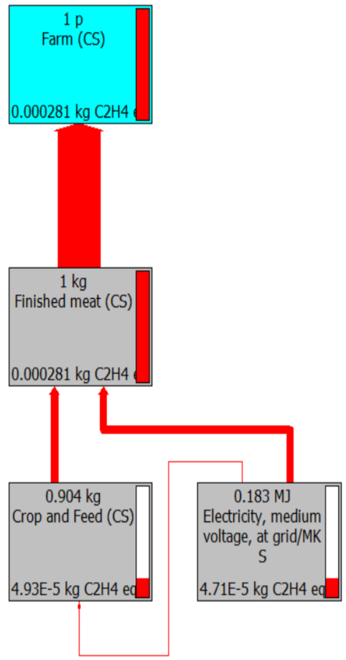

Figure I.19: NFC referred to PhOP

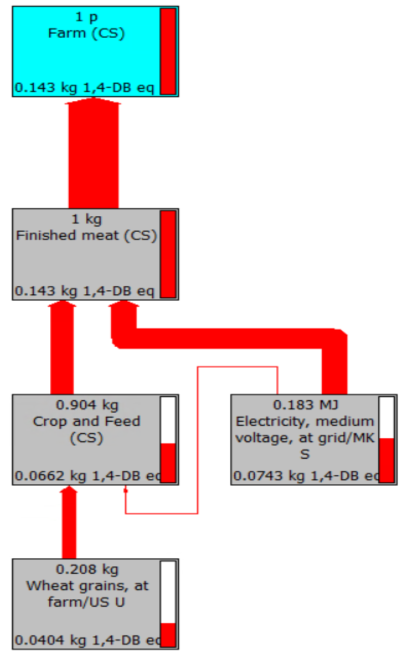

Figure I.20: NFC referred to FAETP

Scenario 2 (Feed and Crop Production): Network chart flows (NCF), which refers to impact categories resulted from CML 2001 method

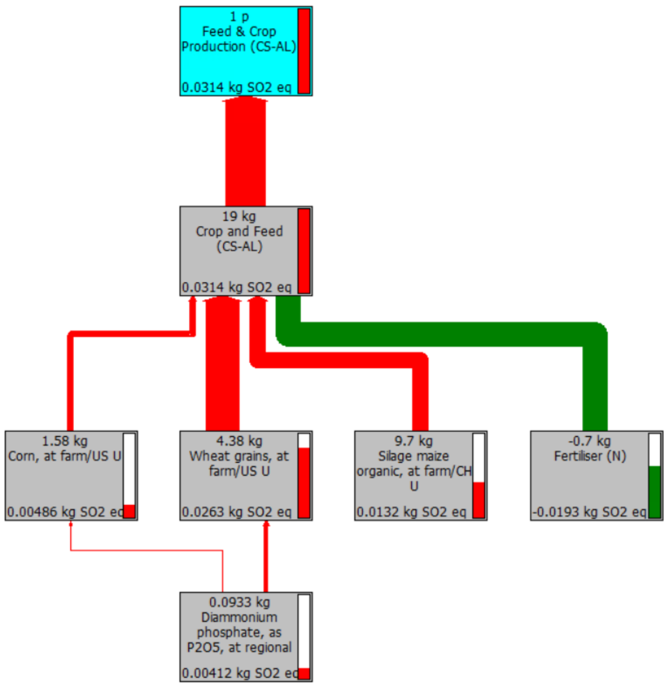

Figure I.21: NFC referred to AP

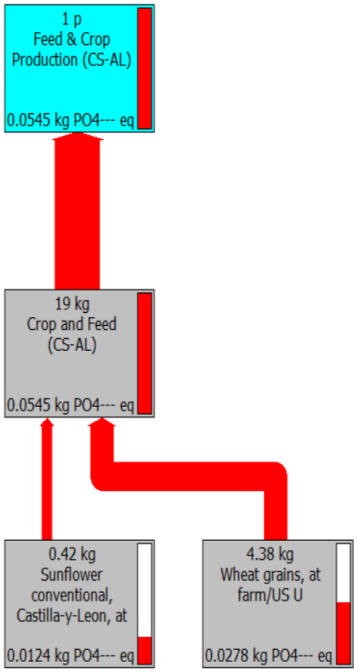

Figure I.22: NFC referred to EP

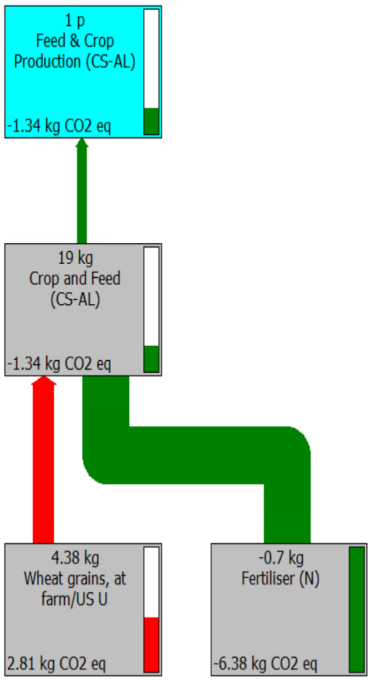

Figure I.23: NFC referred to GWP

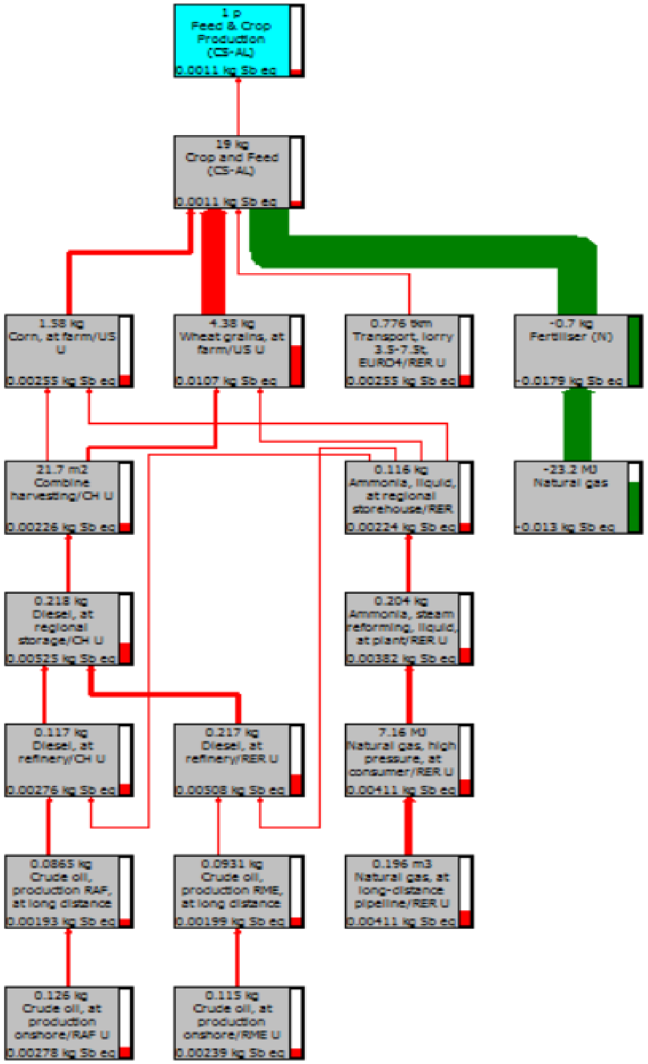

Figure I.24: NFC referred to ADP

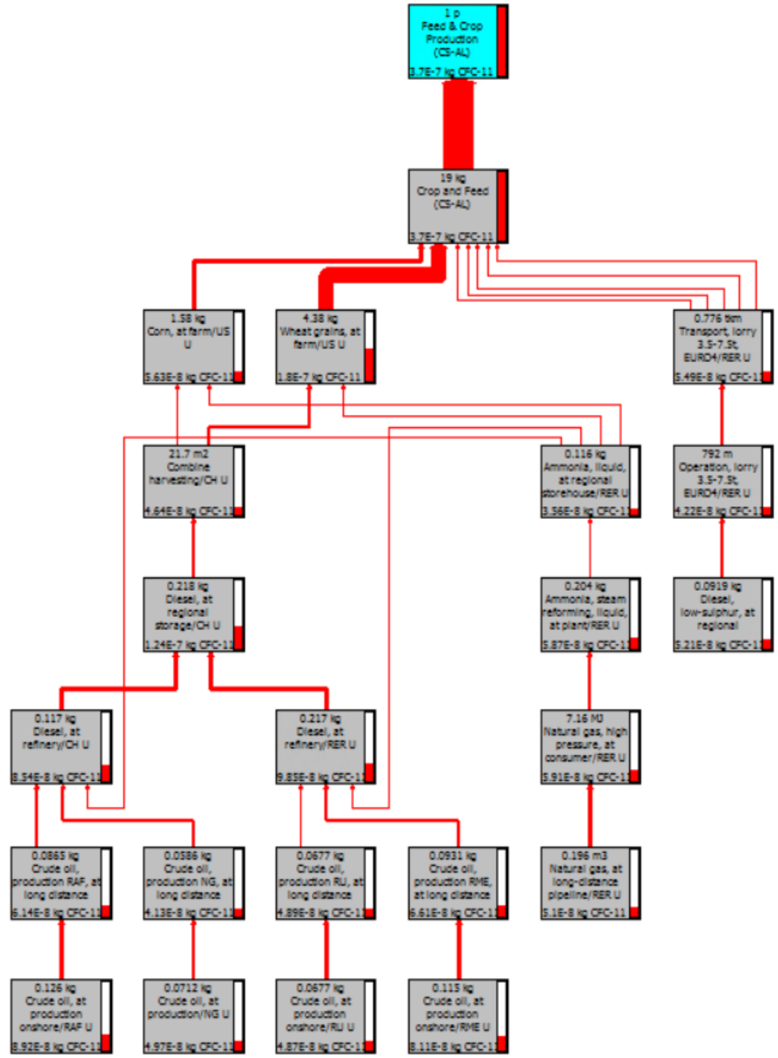

Figure I.25: NFC referred to ODP

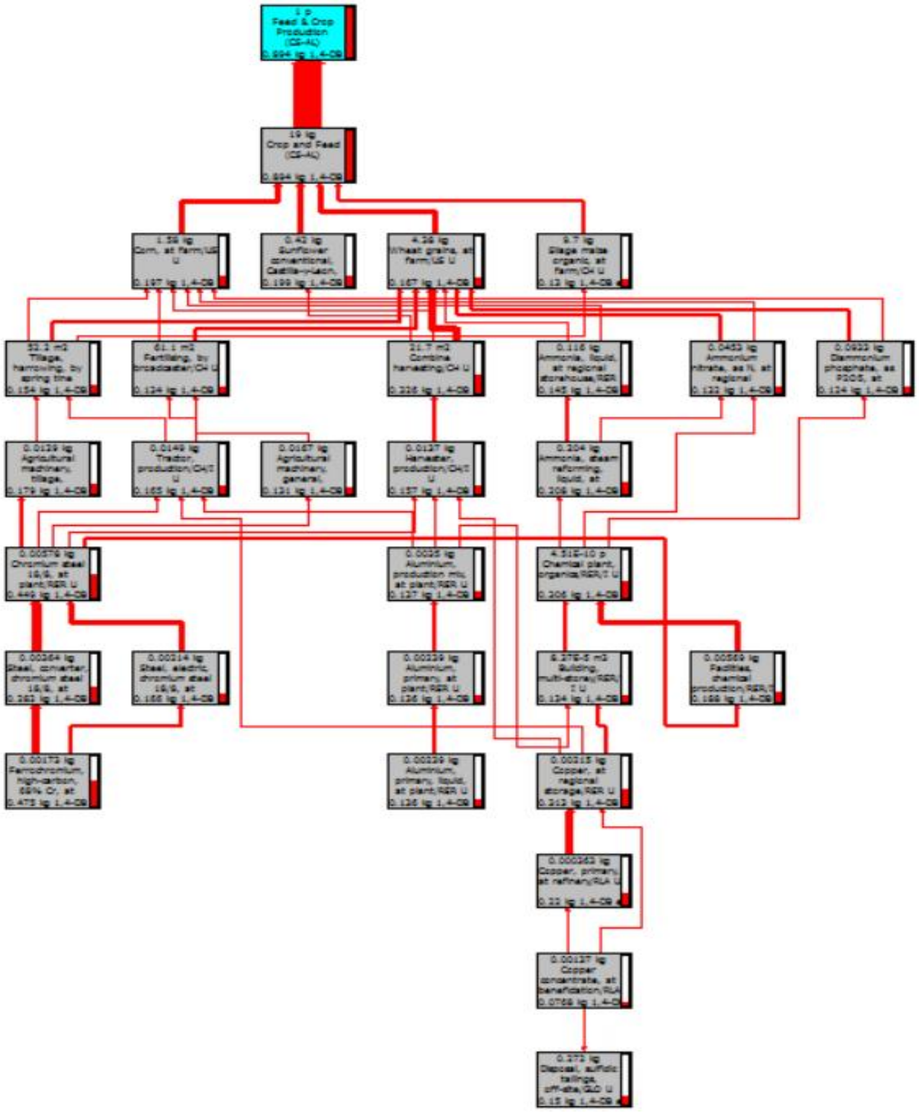

Figure I.26: NFC referred to HTP

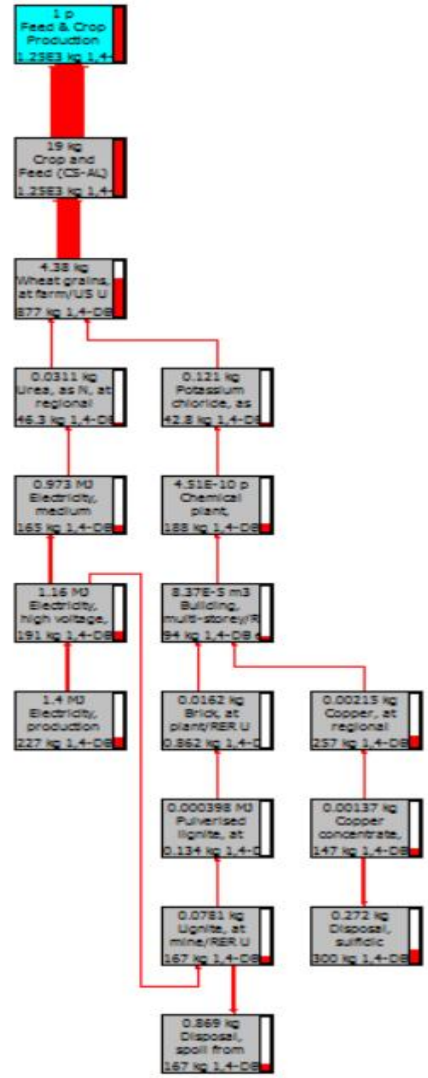

Figure I.27: NFC referred to MAETP

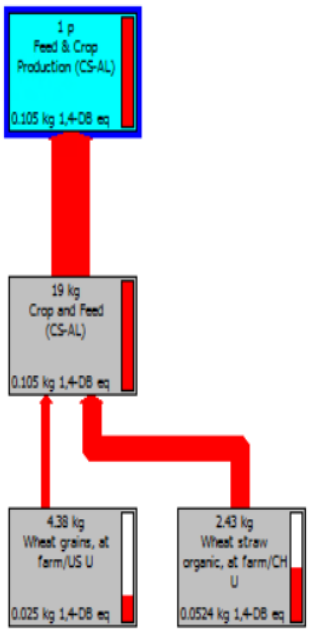

Figure I.28: NFC referred to TEP

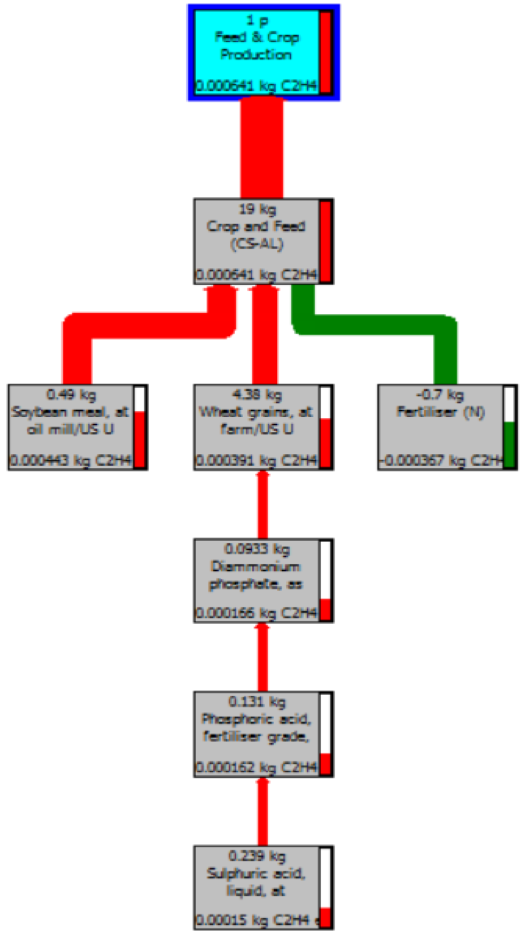

Figure I.29: NFC referred to PhOP

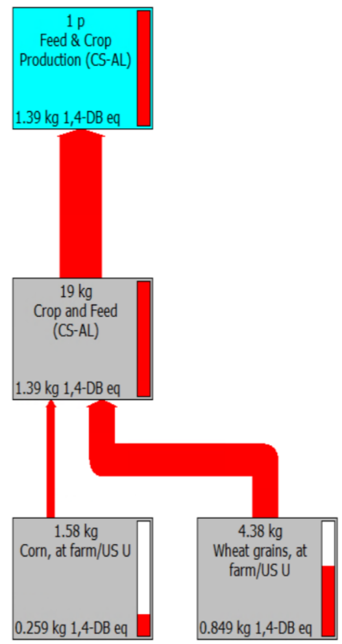

Figure I.30: NFC referred to FAETP

Scenario 2 (Farm): Network chart flows (NCF), which refers to impact categories resulted from CML 2001 method

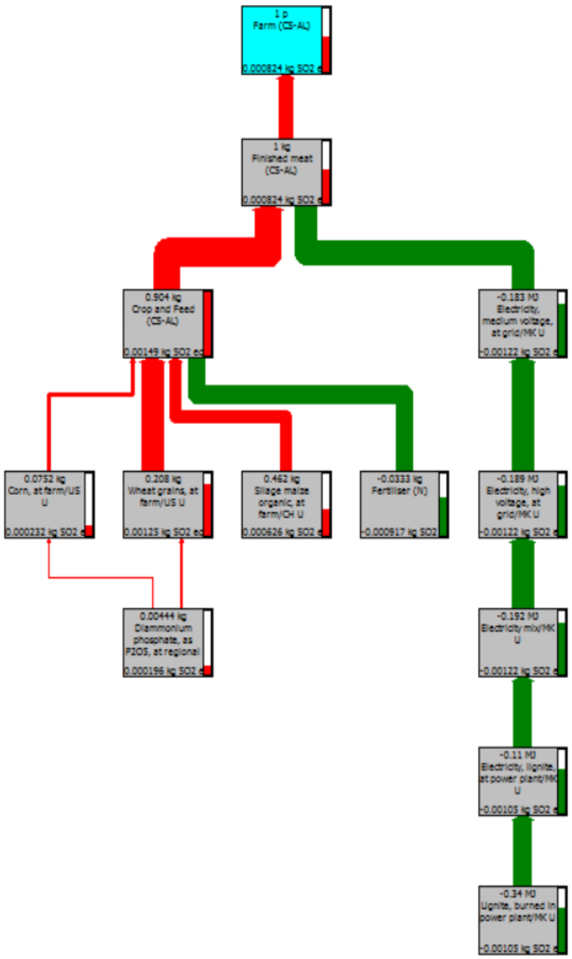

Figure I.31: NFC referred to AP

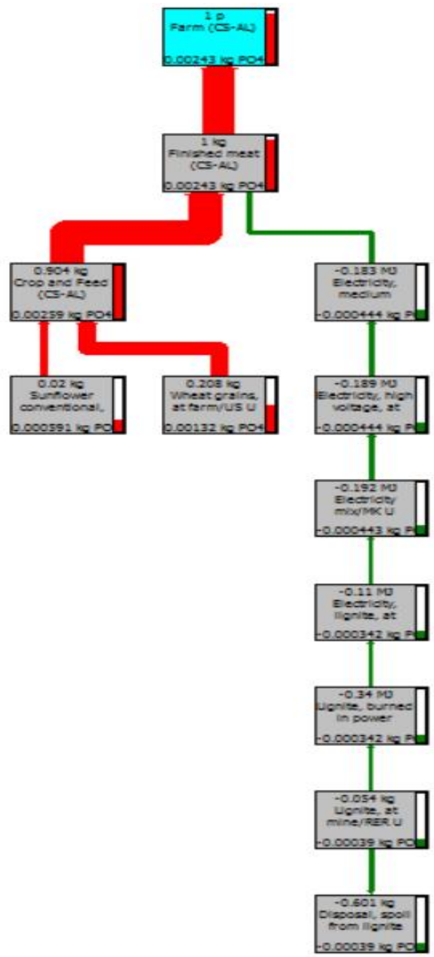

Figure I.32: NFC referred to EP

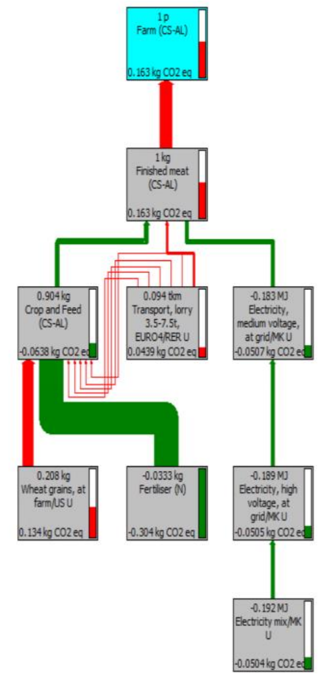

Figure I.33: NFC referred to GWP

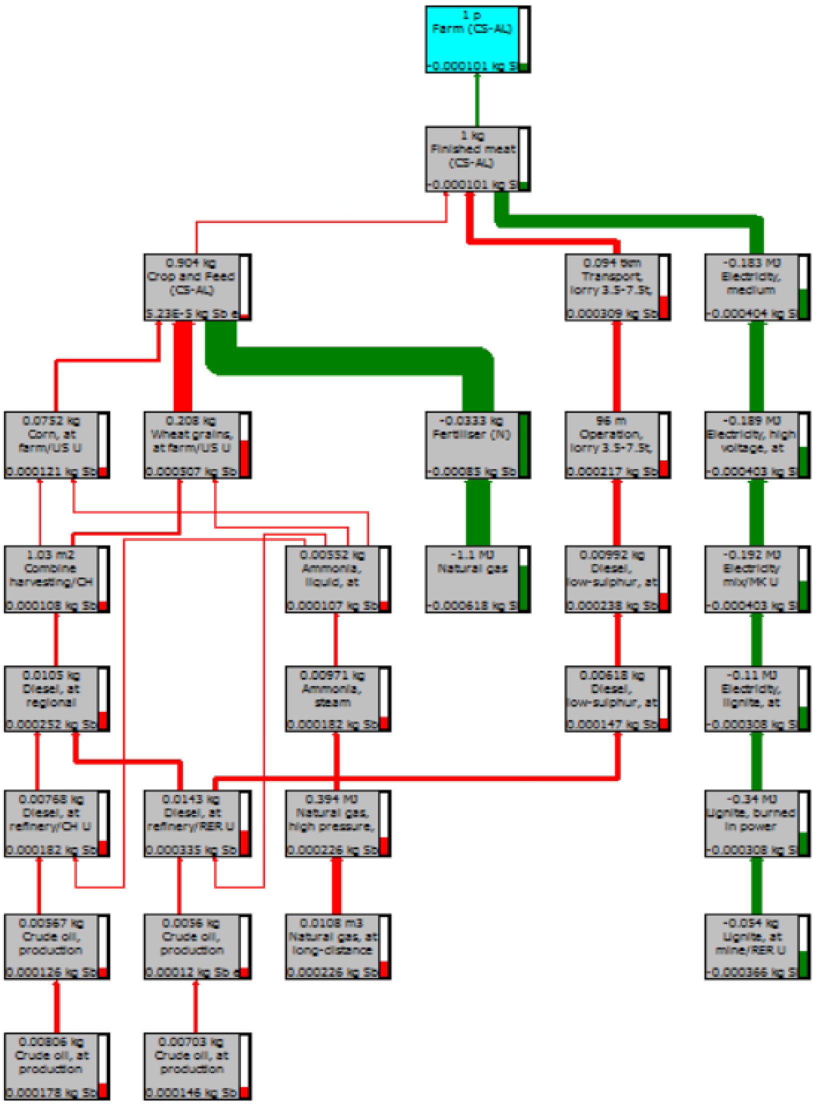

Figure I.34: NFC referred to ADP

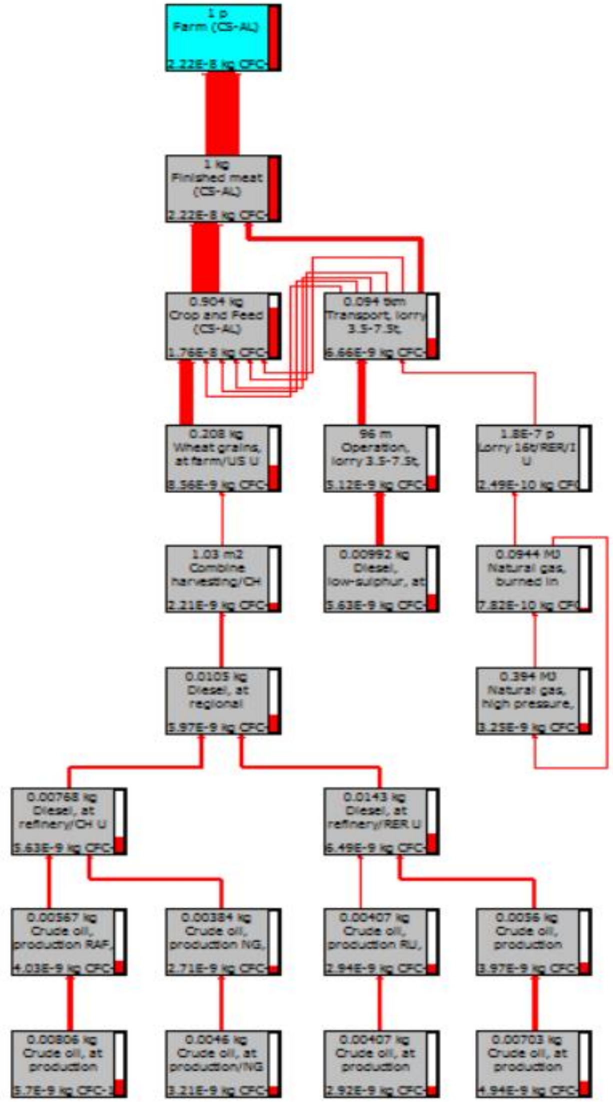

Figure I.35: NFC referred to ODP

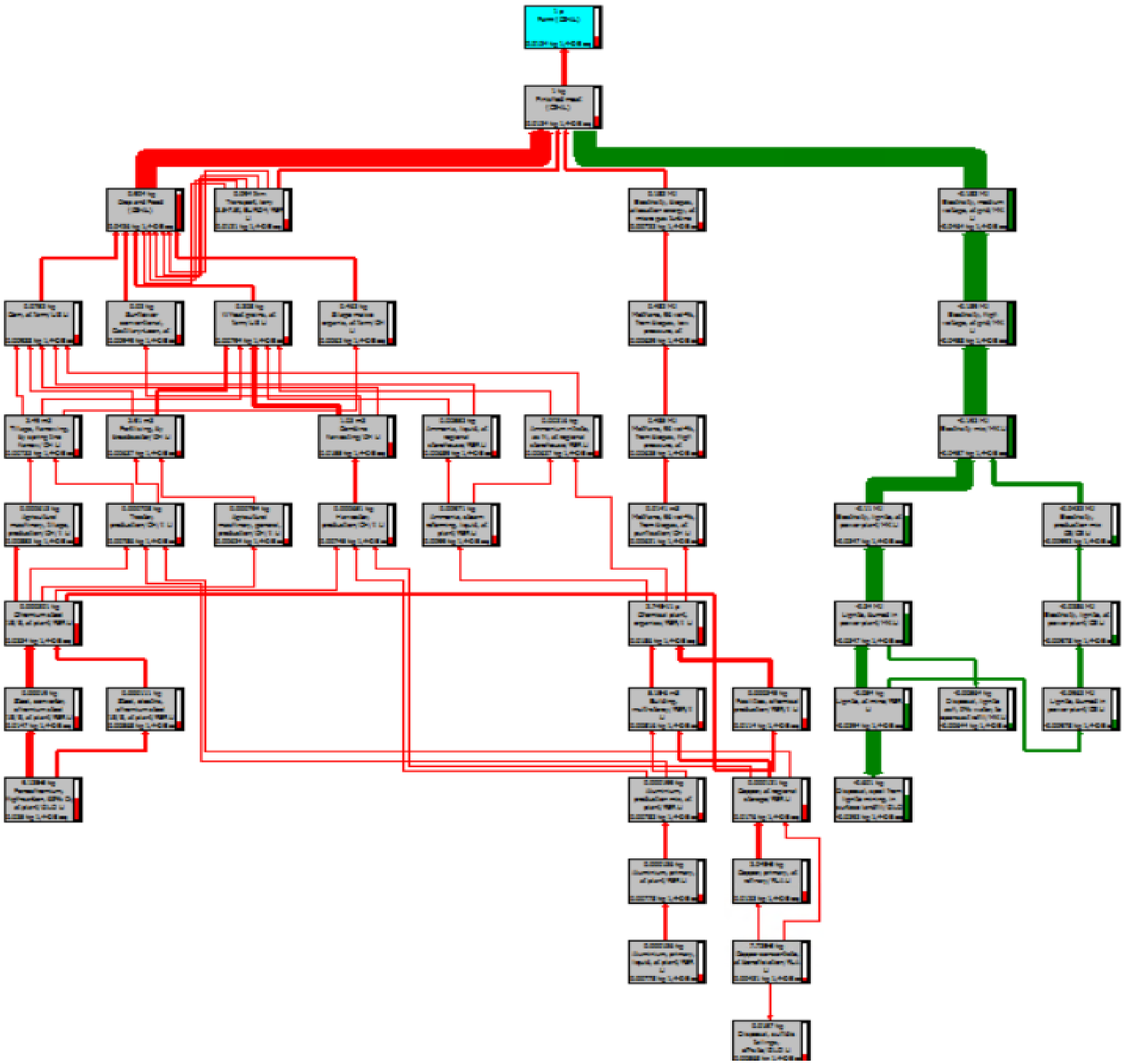

Figure I.36: NFC referred to HTP

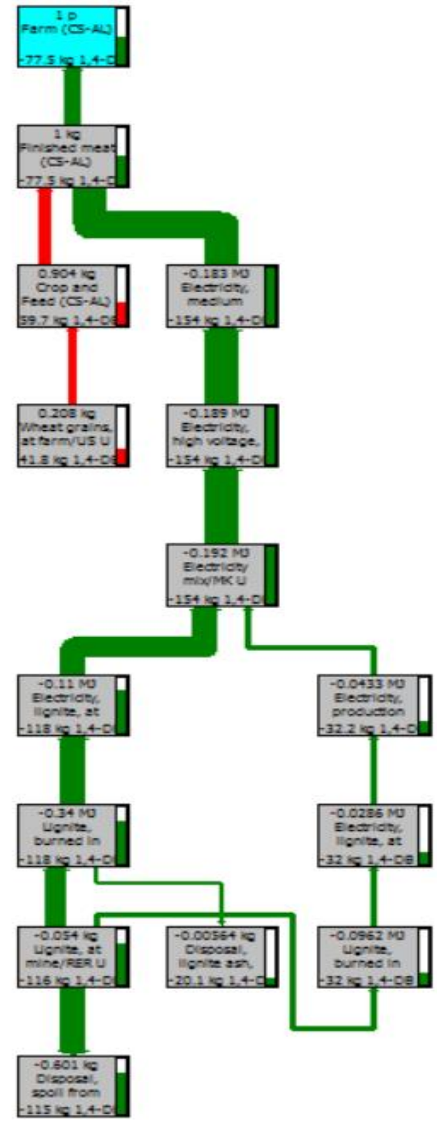

Figure I.37: NFC referred to MAETP

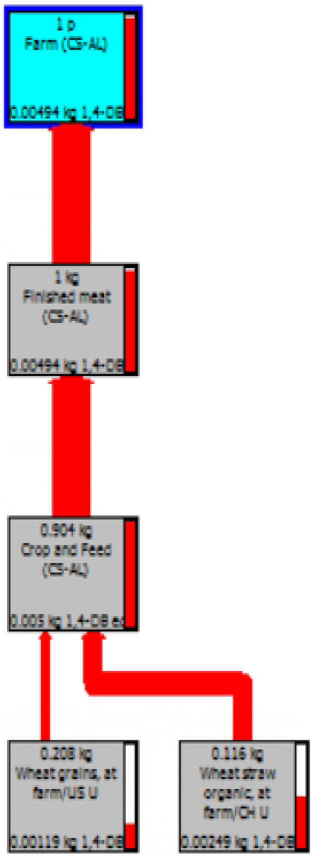

Figure I.38: NFC referred to TEP

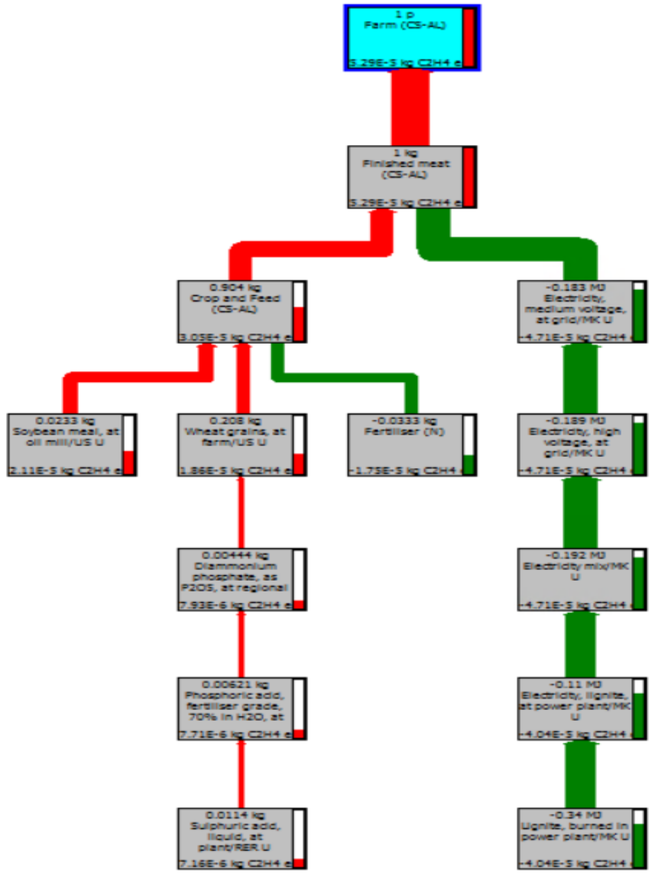

Figure I.39: NFC referred to PhOP

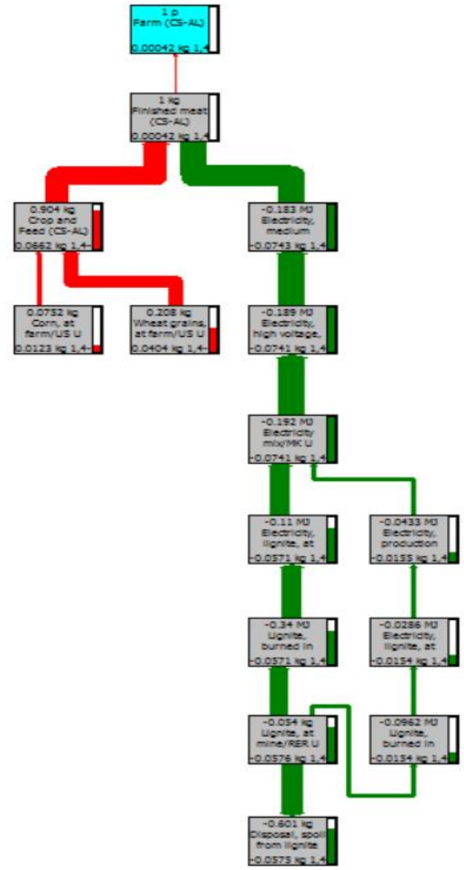

Figure I.40: NFC referred to FAETP